27
6-6-75
25 sep 75
XITS

BNWL-B-378
Special Distribution
in UC-70

Solubility of Elements in U.S. Western Desert Ground Water and Comparison with Chemical and Radiological Concentration Limits for Drinking Water

February 1975

**Prepared for the U.S. Energy
Research and Development Administration
under Contract AT(45-1):1830**

Battelle

Pacific Northwest Laboratories

MASTER

DISTRIBUTION OF THIS DOCUMENT UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or thier employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
U.S. ATOMIC ENERGY COMMISSION
Under Contract AT(45-1)-1830

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151
Price: Printed Copy \$5.45; Microfische \$2.25

SOLUBILITY OF ELEMENTS IN U.S. WESTERN
DESERT GROUND WATER AND COMPARISON
WITH CHEMICAL AND RADIOLOGICAL
CONCENTRATION LIMITS FOR DRINKING WATER

by T. R. Card
NORCUS Appointee
and G. Jansen
Process Evaluation Section
Nuclear Waste Technology Department

February 1975

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

On January 19, 1975, research and development programs of the U.S. Atomic Energy Commission (AEC) became part of the newly formed Energy Research and Development Administration (ERDA). In this report, since it refers to work done in 1974, most references are to AEC programs.

Battelle
Pacific Northwest Laboratories
Richland, Washington 99352

MASTER

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

CONTENTS

LIST OF TABLES	v
SUMMARY	1
INTRODUCTION	3
ESTIMATION OF SOLUBILITIES OF ELEMENTS IN GROUND WATER	4
COMPARISON OF SOLUBILITIES WITH CHEMICAL TOXICITIES	8
COMPARISON OF SOLUBILITIES WITH RADIOTOXICITIES	11
APPENDIX A: Methodology for Estimating Solubilities	17
APPENDIX B: Comparison of Solubilities in Ground Water with Radiotoxicities and Chemical Toxicities	23
APPENDIX C: Basic Language Computer Programs and Files for UNIVAC 1108	37
REFERENCES	51
DISTRIBUTION	53

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

LIST OF TABLES

1	Solubility of the Elements Compared with Recommended Chemical Concentration Limits	5
2	Elements Less Soluble in Typical Ground Water Than Recommended Chemical Concentration Limits	9
3	Radionuclides in High-Level Waste for Which the Element Solubility in Ground Water Is Less Than the Chemical Maximum Permissible Limit in Drinking Water	10
4	Comparison of Element Solubility with Radiotoxicity and Chemical Toxicity for Selected Radionuclides Found in High-Level Waste	13
5	Radionuclides in High-Level Waste for Which Element Solubility in Ground Water Is Lower Than Radiological RCG from 10CFR20	14
6	Radionuclides in High-Level Waste for Which Element Solubility in Ground Water Is in the Range 1 to 10,000 Times the RCG from 10CFR20	15
7	Radionuclides in High-Level Waste for Which Radiotoxicity Is Less Than Chemical Toxicity	15
8	Radionuclides in High-Level Waste for Which Radiotoxicity Is 1 to 10,000 Times Greater Than the Chemical Toxicity	16

SOLUBILITY OF ELEMENTS IN U.S. WESTERN DESERT GROUND
WATER AND COMPARISON WITH CHEMICAL AND RADIOLOGICAL
CONCENTRATION LIMITS FOR DRINKING WATER

SUMMARY

The solubilities for 96 elements in typical western U.S. desert ground water were estimated along with the degrees of reliability of the estimate for each element. Because of the many simplifying assumptions needed in this evaluation, the results should be used only for preliminary screening purposes or for demonstrating the utility of the methodology. The major insoluble chemical species were hydroxides (44 elements), carbonates (11 elements), sulfates (5 elements) and anionic or nonionic forms (19 elements).

Comparison of the solubilities of the elements with drinking water limits for chemicals indicates that 23 elements may not be soluble enough in ground water to reach chemically toxic limits. These elements include radioisotopes of carbon, cobalt, zirconium, ruthenium, palladium, tin, lead, thorium, uranium, plutonium, and americium found in high-level wastes.

Comparison of the solubilities of radionuclides with the 10CFR20 Recommended Concentration Guide for radionuclides in drinking water shows that the major long-lived isotopes of zirconium, palladium, tin, thorium, uranium, and possibly plutonium may be too insoluble in drinking water obtained from the ground water supply to become a radiological hazard from buried waste.

A few radionuclides such as PD-107, Th-232, U-235, U-238 and possibly Pu-242 found in high-level wastes may reach chemically toxic concentrations in drinking water before 10CFR20 radionuclide limits are exceeded.

If isotopic dilution of several radionuclides by factors up to 10,000 could be achieved, the radiological hazard might be decreased below 10CFR20 limits in buried waste by lowering the radioactivity of ground water saturated

in that chemical element. This isotopic dilution might be expected to occur naturally over long travel paths within geologic formations or might be introduced by isotopically diluting stored waste itself.

INTRODUCTION

If a hypothetical water leaching incident occurs at a geologic storage site for high-level radioactive wastes, ground water may carry trace quantities of the wastes many miles into drinking water supplies. The currently accepted concentration limits of radioactivity in drinking water for the general population are given in Table II, Appendix B, of 10CFR20.⁽¹⁾ The allowable chemical concentrations of these elements in drinking water have also been documented by G. W. Dawson.⁽²⁾ A preliminary estimate of the rate of migration of adsorbing or precipitating nuclides relative to water flow has also been made.⁽³⁾ It may be true, however, that the solubility of many of the radioactive elements in drinking water is so low that the allowable radiological and chemical limits cannot be reached.

This study deals with an attempt to estimate for those elements found in radioactive wastes the solubility in ground water which could be used as a source of drinking water. The approach is highly simplified and ignores some factors that could be important, but it is hoped that this systematic approach, though necessarily inaccurate, will stimulate gathering of better data. Only the gross inorganic components of an alkaline ground water typical of that in the western U.S. desert are considered. Some soluble inorganic complexes may not be taken into account, and naturally occurring organic materials (such as humic acids and biological agents released by plant roots which would tend to increase the solubility of minerals) are not included. A good example of the caution to be attached to these results is the case of ruthenium. Calculations based on the simplified assumptions used in this work predict it to be quite insoluble, but it is well known that ruthenium, because of its many valence states, can migrate freely with ground water flow.

Ground water is continually interacting with the complex minerals found in the earth's crust. Thus the simple compounds assumed in this work to occur may in fact be represented in nature by appreciably more soluble or insoluble complex minerals. The surface properties and degree of subdivision

of mineral solids, the formation of nonequilibrium minerals, and temperature effects also affect the actual concentrations of radionuclides in ways that cannot be predicted by simple solubilities. Radiocolloids have been known to precipitate at concentrations much lower than those estimated from solubility products.⁽⁴⁾ Finally, materials found in the waste may interact to form more insoluble or soluble species. For example, fluoride complexes zirconium, and organic complexing agents such as EDTA (ethylenediaminetetraacetic acid) form highly stable complexes with nearly all multivalent cations.

ESTIMATION OF SOLUBILITIES OF ELEMENTS IN GROUND WATER

Table 1 has been constructed to enumerate the solubilities of the elements in the periodic table up to atomic number 96 in typical western U.S. desert ground water. The methods used for estimating the solubilities are given in Appendix A. The assumed typical ground water has a pH of 6.8 to 8.2, sulfate 15 to 61 ppm, nitrate 1 ppm, chloride 8 to 46 ppm, bicarbonate 125 to 242 ppm, sodium 20 to 51 ppm, potassium 5 to 7 ppm, calcium 25 to 54 ppm, magnesium 5 to 20 ppm, silicate (nonionic SiO_2) 44 ppm.⁽³⁾

When complete data were available the solubility was calculated by means of solubility product of an element (in the most common valence state expected in ground water) with each separate ion applicable; i.e., if the element existed in solution in a cationic form, the solubility was calculated with each separate anion in solution. After calculations with each separate ion, the solution ion that precipitated the element in question at the lowest concentration was determined. For each element the highest solubility of the most insoluble species within the range of ground water compositions was used. This concentration in milligrams per liter was then entered in Table 1 along with the insoluble species.

For the elements for which incomplete data or no data at all was available, extrapolation techniques were derived to estimate the solubility of compounds of these elements. Such extrapolations are approximations at best and should be viewed as such. The basis upon which each soluble concentration

**TABLE 1. Solubility of the Elements Compared
with Recommended Chemical Concentration Limits**

Atomic Number	Element	Valence States	Potable Water Limit, mg/l (2)	Solubility, mg/l	Undissolved Species	Basis	Ref.	Ratio of Solubility to Potable Water Limit
1	H	1	110,000	110,000	H ₂ O	A-1	5	1.0
1	D,T	1	3,500	300,000	T ₂ O	A-1	5	86
2	He	0	0.2	2	He	B	6	10
3	Li	1	5	100,000	Li ₂ CO ₃	A	7	20,000
4	Be	2	1	2.5x10 ⁻⁵	Be(OH) ₂	C-1	8	2.5x10 ⁻⁵
5	B	3	1	13,000	CaB ₂ O ₄	A	7	13,000
6	C	4	400	0.06	CaCO ₃	A	8	1.5x10 ⁻⁴
7	N	5	0.1	100,000	NaN ₃	A	7	1x10 ⁶
8	O	2	890,000	890,000	H ₂ O	A-3	5	1.01
9	F	1	1.0	35	CaF ₂	A	9	3.5
10	Ne	0	1	1,600	Ne	B	10	1,600
11	Na	1	1,000	100,000	Na ₂ CO ₃	A	7	100
12	Mg	2	10	34,000	MgCO ₃	A	8	3,400
13	Al	3	0.01	4x10 ⁻¹⁰	Al(OH) ₃	C-2	9	4x10 ⁻⁸
14	Si	4	5	56	SiO ₂	C-27	7	11
15	P	5	0.01	4.4x10 ⁻⁶	Ca ₃ (PO ₄) ₂	A	8	4.4x10 ⁻⁴
16	S	6	50	800	CaSO ₄	A	8	16
17	Cl	1	125	300,000	KCl	A	7	2,400
18	Ar	0	10	71	Ar	B	10	7.1
19	K	1	1,000	400,000	K ₂ SO ₄	A	7	400
20	Ca	2	30	54	CaCO ₃	A	11	1.8
21	Sc	3	0.5	3x10 ⁻⁷	Sc(OH) ₃	C-3	8	6x10 ⁻⁷
22	Ti	4	0.1	4x10 ⁻¹⁷	Ti(OH) ₄	C-4	8	4x10 ⁻¹⁶
23	V	4	0.1	1.5x10 ⁻⁵	H ₂ VO ₃	C-5	8	1.5x10 ⁻⁴
24	Cr	6	0.02	100,000	CaCrO ₄	A	7	5x10 ⁶
25	Mn	2	0.01	0.7	Mn(OH) ₂	A	9	70
26	Fe	3	0.05	1.8x10 ⁻⁹	Fe(OH) ₃	A	8	3.6x10 ⁻⁸
27	Co	2	0.05	8x10 ⁻³	CoCO ₃	A	9	0.16
28	Ni	2	0.05	50	NiCO ₃	A	11	1,000
29	Cu	2	0.01	1.4x10 ⁻²	Cu(OH) ₂	A	12	1.4

TABLE 1. (continued) Solubility of the Elements
Compared with Recommended Chemical Concentration Limits

Atomic Number	Element	Valence States	Potable Water Limit, mg/l (2)	Solubility, mg/l	Undissolved Species	Basis	Ref.	Ratio of Solubility to Potable Water Limit
30	Zn	2	0.05	1	ZnCO ₃	A	9	20
31	Ga	3	0.2	3×10^{-13}	Ga(OH) ₃	C-6	9	1.5×10^{-11}
32	Ge	4	0.5	6	Mg ₂ GeO ₄	A	7	12
33	As	5	0.01	1	Mg ₃ (AsO ₄) ₂	A	8	100
34	Se	4	0.01	240	CaSeO ₃	A	8	24,000
35	Br	1	--	700,000	NaBr	A	7	--
36	Kr	0	40	300	Kr	B	10	7.5
37	Rh	1	50	500,000	Rh ₂ SO ₄	A	7	10,000
38	Sr	2	10	11	SrCO ₃	A	12	1.1
39	Y	3	0.001	56	Y(OH) ₃	C-7	8	56,000
40	Zr	4	1.0	1×10^{-25}	Zr(OH) ₄	C-8	8	1×10^{-25}
41	Nb	5	0.02	9×10^{-3}	Ca(NbO ₃) ₂	A	8	0.45
42	Mo	6	0.5	700	H ₂ MoO ₄	A	10	1,400
43	Tc	3	100	100	H ₃ TeO ₃	D	13	1
44	Ru	3	1	8×10^{-16}	Ru(OH) ₃	C-9	8	8×10^{-16}
45	Rh	3	0.05	8×10^{-10}	Rh(OH) ₃	C-10		1.6×10^{-8}
46	Pd	2	0.05	4×10^{-17}	Pd(OH) ₂	C-11	8	8×10^{-16}
47	Ag	1	0.001	0.03	AgCl	A	11	30
48	Cd	2	0.01	4×10^{-4}	CdCO ₃	A	9	0.04
49	In	3	0.02	5×10^{-10}	In(OH) ₃	C-12	8	2.5×10^{-8}
50	Sn	4	0.05	1.9×10^{-26}	Sn(OH) ₄	C-13	9	3.8×10^{-25}
51	Sb	3	0.05	2.5×10^{-6}	SbOOH	C-14	9	5×10^{-5}
52	Te	4	0.2	5	TeO ₂	C-15	7	25
53	I	1	10	600,000	CaI ₂	A	7	60,000
54	Xe	0	150	1,000	Xe	B	10	6.7
55	Cs	1	5	600,000	CsNO ₃	A	7	120,000
56	Ba	2	0.5	0.04	BaSO ₄	A	9	0.08
57	La	3	1.0	10,000	La(OH) ₃	A	9	10,000
58	Ce	3	2.0	13,000	Ce(OH) ₃	C-16	14	6,500
59	Pr	3	1.0	30,000	Pr(OH) ₃	C-16	14	30,000
60	Nd	3	0.2	2,200	Nd(OH) ₃	C-16	14	1,100
61	Pm	3	1.0	1,200	Pm(OH) ₃	E	13	1,200
62	Sm	3	0.2	810	Sm(OH) ₃	C-16	14	4,050
63	Eu	3	0.2	410	Eu(OH) ₃	C-16	15	2,050
64	Gd	3	0.2	260	Gd(OH) ₃	C-16	14	1,300

TABLE 1. (continued) Solubility of the Elements
Compared with Recommended Chemical Concentration Limits

Atomic Number	Element	Valence States	Potable Water Limit, mg/l (2)	Solubility, mg/l	Undissolved Species	Basis	Ref.	Ratio of Solubility to Potable Water Limit
65	Tb	3	0.5	160	Tb(OH) ₃	E	13	320
66	Pr	3	1.0	100	Dy(OH) ₃	E	13	100
67	Ho	3	1.0	50	Hd(OH) ₃	E	13	50
68	Er	3	0.1	20	Er(OH) ₃	C-16	14	200
69	Tm	3	0.2	5	Tm(OH) ₃	C-16	14	25
70	Yb	3	0.1	4	Yb(OH) ₃	C-16	14	40
71	Lu	3	0.1	0.15	Lu(OH) ₃	C-16	14	1.5
72	Hf	4	0.05	100,000*	Hf(OH) ₄	C-17	8	2x10 ⁶
73	Ta	5	1.0	100	Ca(TaO ₃) ₂	D	13	100
74	W	6	500	2	CaWO ₄	A	8	0.004
75	Re	3	10	100	H ₃ ReO ₃	D	13	10
76	Os	8	--	45,000	OsO ₄	C-18	7	--
77	Ir	3	0.8	2	Ir ₂ O ₃	C-19	7	2.5
78	Pt	2	0.3	8x10 ⁻¹⁸	Pt(OH) ₂	C-20	8	2.7x10 ⁻¹⁷
79	Au	3	0.02	9x10 ⁻²²	Au(OH) ₃	C-20	8	4.5x10 ⁻²⁰
80	Hg	2	0.002	1.4x10 ⁻⁸	Hg(OH) ₂	A	9	7x10 ⁻⁶
81	Tl	1	0.005	4x10 ⁴	TlCl	A	9	8x10 ⁶
82	Pb	2	0.01	9.5x10 ⁻⁴	PbCO ₃	A	8	9.5x10 ⁻²
83	Bi	3	0.5	1	BiOOH	C-21	9	2
84	Po	4	0.2	100	PoO ₂	F	13	500
85	At	1	10	500,000	CaAt ₂	G	13	50,000
86	Rn	0	500	10,000	Rn	B	10	20
87	Fr	1	5	600,000	FrNO ₃	G	13	120,000
88	Ra	2	0.001	0.025	RaSO ₄	C-22	8	25
89	Ac	3	0.02	200,000	Ac ₂ (OH) ₃	C-23	7	1x10 ⁷
90	Th	4	0.0005	1.5x10 ⁻¹⁴	Th(OH) ₄	C-20	14	3x10 ⁻¹¹
91	Pa	5	0.01	10	PaO ₂ OH	H	13	1,000
92	U	6	0.5	9.5x10 ⁻⁵	UO ₂ (OH) ₂	C-24	16	1.9x10 ⁻⁴
93	Np	5	0.008	500	NpO ₂ OH	C-25	16	62,000
94	Pu	4	0.0008	2.7x10 ⁻⁵	PuO ₂	C-29	17	3.4x10 ⁻²
95	Am	3	0.04	4,000	Am(OH) ₃	C-26	18	100,000
96	Cm	3	0.5	40,000	Cm(OH) ₃	C-26	18	80,000

* This is much higher than for its homolog zirconium. The thermodynamic data for hafnium in Reference 8 may be in error.

was set is referred to in an adjoining column labelled "Basis." The letter code of the basis refers to the procedure followed to derive the solubility as outlined in Appendix A. Numerical subcodes refer to specific nuances employed for the element in question and are also explained in Appendix A. Adjoining columns contain the reference from which the initial solubility data was taken, the potable water limit with respect to chemical toxicity, and the ratio of the elemental solubility to the potable water limit. In developing the various bases employed to generate solubility values, reliability was found to be a strong function of the type of data that was available. The matrix below indicates the level of reliability placed in each of the techniques employed.

	Reliability		
	High	Lower	Lowest
General Basis	A	C	D
Code	B	E	F
			G
			H

Because of the extrapolation techniques required to derive the solubilities selected, many of these numbers are approximations at best. They are generally conservative and may be much higher than the actual physical solubilities. To improve these estimates more reliable data are required for solubilities of the lesser known elements and on characteristics of ground water in contact with soils.

COMPARISON OF SOLUBILITIES WITH CHEMICAL TOXICITIES

Table 1 gives the ratios of the solubilities of the elements in ground water to maximum permissible chemical concentrations in potable water selected from among those estimated by Dawson.⁽²⁾ Most of the elements are soluble in excess of drinking water limits based on chemical toxicities. The elements not soluble enough to exceed this drinking water limit are tabulated in Table 2. They include 23 elements, most of which have relatively insoluble hydroxides.

TABLE 2. Elements Less Soluble in Typical Ground Water
Than Recommended Chemical Concentration Limits

Element	Potable Water Limit, mg/l (2)	Assumed Undissolved Species	Ratio of Solubility to Potable Water Limit
Beryllium	1	Be(OH) ₂	2.5×10^{-5}
Carbon	400	CaCO ₃	1.5×10^{-4}
Aluminum	0.01	Al(OH) ₃	4×10^{-8}
Phosphorus	0.01	Ca ₃ (PO ₄) ₂	4.4×10^{-4}
Scandium	0.5	Sc(OH) ₃	6×10^{-7}
Titanium	0.1	Ti(OH) ₄	4×10^{-16}
Vanadium	0.1	H ₂ VO ₃	1.5×10^{-4}
Iron	0.05	Fe(OH) ₃	3.6×10^{-8}
Gallium	0.2	Ga(OH) ₃	1.5×10^{-11}
Zirconium	1.0	Zr(OH) ₄	1×10^{-25}
Ruthenium	1	Ru(OH) ₃	8×10^{-16}
Rhodium	0.05	Rh(OH) ₃	1.6×10^{-8}
Palladium	0.05	Pd(OH) ₂	8×10^{-16}
Indium	0.02	In(OH) ₃	2.5×10^{-8}
Tin	0.05	Sn(OH) ₄	3.8×10^{-25}
Antimony	0.05	SbOOH	5×10^{-5}
Platinum	0.3	Pt(OH) ₂	2.7×10^{-17}
Gold	0.02	Au(OH) ₃	4.5×10^{-20}
Mercury	0.002	Hg(OH) ₂	7×10^{-6}
Lead	0.01	PbCO ₃	9.5×10^{-2}
Thorium	0.0005	Th(OH) ₄	3×10^{-11}
Uranium	0.5	UO ₂ (OH) ₂	1.9×10^{-4}
Plutonium	0.0008	PuO ₂	3.4×10^{-2}

A selected list of the radionuclides found in high-level waste, shown in Table 3, falls into the category of elements not soluble enough to exceed their potable water limits as chemicals. These include isotopes of carbon, cobalt, zirconium, ruthenium, palladium, tin, antimony, lead, thorium, uranium, plutonium and americium. The inclusion of ruthenium in this list indicates that there is room for error in the method used for estimating solubilities.

TABLE 3. Radionuclides in High-Level Waste for Which the Element Solubility in Ground Water Is Less Than the Chemical Maximum Permissible Limit in Drinking Water

NUCLIDE	HALF-LIFE	CHEMICAL	CHEMICAL	CHEMSOL /
	YR	SOLUBILITY	MPL	MPL
		MG/L	MG/L	
C 14	5.7E+03	6.0E-02	4.E+02	1.5E-04
CO 60	5.3E+00	8.0E-03	5.E-02	1.6E-01
ZR 93	9.5E+05	1.0E-25	1.E+00	1.0E-25
RU106	1.0E+00	8.0E-16	1.E+00	8.0E-16
PD107	6.5E+06	4.0E-17	5.E-02	8.0E-16
SN126	1.0E+05	2.0E-26	5.E-02	4.0E-25
SB125	2.7E+00	2.5E-06	5.E-02	5.0E-05
PB210	2.2E+01	9.5E-04	1.E-02	9.5E-02
TH228	1.9E+00	1.5E-14	5.E-02	3.0E-13
TH230	7.7E+04	1.5E-14	5.E-02	3.0E-13
TH232	1.4E+10	1.5E-14	5.E-02	3.0E-13
U 233	1.6E+05	9.5E-05	5.E-01	1.9E-04
U 234	2.4E+05	9.5E-05	5.E-01	1.9E-04
U 235	7.0E+08	9.5E-05	5.E-01	1.9E-04
U 236	2.3E+07	9.5E-05	5.E-01	1.9E-04
U 238	4.5E+09	9.5E-05	5.E-01	1.9E-04
PU238	8.8E+01	3.0E-25	8.E-04	3.7E-02
PU239	2.4E+04	3.0E-25	8.E-04	3.7E-02
PU240	6.5E+03	3.0E-25	8.E-04	3.7E-02
PU241	1.5E+01	3.0E-25	8.E-04	3.7E-02
PU242	3.9E+05	3.0E-25	8.E-04	3.7E-02
AM243	7.4E+03	4.0E+03	4.E+04	1.0E-01

COMPARISON OF SOLUBILITIES WITH RADIOTOXICITIES

The solubilities of the long-lived radionuclides found in high-level radioactive wastes are compared in Table 4 with the Recommended Concentration Guides for the general population from Table II, Appendix B, of 10CFR20. Ratios of (a) the radiological concentration guide to the solubility, (b) the radiological toxicity to the chemical toxicity⁽¹⁹⁾ and (c) the chemical limit in drinking water to the solubility in ground water are presented in the last three columns.

As shown in Table 5, the RCG from 10CFR20 may be higher than the solubility in desert ground water for long-lived isotopes of zirconium, ruthenium, palladium, tin, thorium, uranium, and possibly plutonium. This would mean that drinking water drawn from wells or rivers near underground repositories is unlikely to contain radiologically toxic concentrations of these nuclides.

For seven other radionuclides listed in Table 6 the ratio of the RCG to the solubility is greater than 10^{-4} . This value could be raised appreciably due to isotopic dilution by dissolved natural elements (except Tc-99 and artificial actinides) found in geologic formations surrounding a repository, by the unavoidable isotopic dilution during creation of high-level waste, or by intentional isotopic dilution of the waste with inert materials.

Comparisons of radiotoxicities with chemical toxicities of radionuclides are given in Table 7 and 8. A few radionuclides, such as isotopes of palladium, natural thorium, natural uranium, and possibly Pu-242 are more toxic chemically than radiologically. However, the radiotoxicity listed here does not usually include the long-lived daughters in their decay chains, which also may be important. Several nuclides may be isotopically diluted so that their chemical toxicities exceed their radiotoxicities. This does not necessarily mean that they will be radiologically innocuous.

APPENDIXES

The methodology for estimating solubilities is given in Appendix A.

Appendix B contains lists of all the radionuclides in the periodic table with half lives greater than one year compared on the same basis as in Tables 3 to 8.

Appendix C contains listings of the BASIC language computer programs used to create Tables 3 to 8 and Appendix B.

TABLE 4. Comparison of Element Solubility with Radiotoxicity and Chemical Toxicity for Selected Radionuclides Found in High-Level Waste

NUCLIDE	HALF-LIFE	IOCFR20	CHEMICAL	CHEM	RADIO	RCG/	RADTOX/	CHEMSOL/
	YR	RCG	SOLUBILITY	MPL	TOXICITY	CHEMSOL	CHEMTX	MPL
		CI/L	MG/L	MG/L	M ³ /G			
H 3	1.2E+01	3.E-03	3.0E+05	3.E+05	3.2E+06	1.0E-12	9.7E+11	1.0E+00
C 14	5.7E+03	8.E-04	6.0E-02	4.E+02	5.6E+03	3.0E-03	2.2E+06	1.5E-04
CU 60	5.3E+00	5.E-05	8.0E-03	5.E-02	2.3E+07	5.5E-06	1.1E+06	1.6E-01
NI 59	8.0E+04	2.E-04	5.0E+01	5.E-02	3.8E+02	5.3E-05	1.9E+01	1.0E+03
NI 63	1.0E+02	3.E-05	5.0E+01	5.E-02	1.9E+06	1.1E-08	9.5E+04	1.0E+03
SR 90	2.9E+01	3.E-07	1.1E+01	1.E+01	4.6E+08	2.0E-10	4.6E+09	1.1E+00
ZR 93	9.5E+05	8.E-04	1.0E-25	1.E+00	5.1E+00	2.0E+24	5.1E+00	1.0E-25
MO 93	3.0E+03	BBBBBB	7.0E+02	2.E-02	4.3E+05	3.3E-09	8.5E+03	3.5E+04
TC 99	2.1E+05	3.E-04	1.0E+02	1.E+02	5.7E+01	1.8E-04	5.7E+03	1.0E+00
RU106	1.0E+00	1.E-05	8.0E-16	1.E+00	3.3E+08	3.7E+06	3.3E+08	8.0E-16
PD107	6.5E+06	1.E-03	4.0E-17	5.E-02	5.1E-01	4.9E+16	2.6E-02	8.0E-16
SN126	1.0E+05	4.E-04	2.0E-26	5.E-02	7.1E+01	7.0E+23	3.5E+00	4.0E-25
SB125	2.7E+00	4.E-04	2.5E-06	5.E-02	2.6E+06	1.5E-01	1.3E+05	5.0E-05
I 129	1.6E+07	6.E-08	6.0E+05	1.E+01	2.9E+03	5.7E-10	2.9E+04	6.0E+04
CS134	2.1E+00	9.E-06	6.0E+05	5.E+00	1.4E+08	1.2E-14	7.2E+08	1.2E+05
CS135	2.3E+06	1.E-04	6.0E+05	5.E+00	1.2E+01	1.4E-07	5.8E+01	1.2E+05
CS137	3.0E+01	2.E-05	6.0E+05	5.E+00	4.3E+06	3.8E-13	2.2E+07	1.2E+05
CE144	7.8E-01	1.E-05	1.3E+04	2.E+00	3.2E+08	2.4E-13	6.4E+08	6.5E+03
PM147	2.6E+00	2.E-04	1.2E+03	1.E+00	4.6E+06	1.8E-10	4.6E+06	1.2E+03
EU152	1.3E+01	8.E-05	4.1E+02	2.E-01	2.3E+06	1.1E-09	4.5E+05	2.0E+03
EU154	8.6E+00	2.E-05	4.1E+02	2.E-01	1.4E+07	1.8E-10	2.7E+06	2.0E+03
EU155	4.8E+00	2.E-04	4.1E+02	2.E-01	2.4E+06	1.0E-09	4.8E+05	2.0E+03
HU166M	1.2E+03	5.E-02	5.0E+01	1.E+00	3.6E+01	5.6E-04	3.6E+01	5.0E+01
PR210	2.2E+01	1.E-07	9.5E-04	1.E-02	7.6E+08	1.4E-06	7.6E+06	9.5E-02
RA226	1.6E+03	3.E-08	2.5E-02	1.E-03	3.3E+07	1.2E-06	3.3E+04	2.5E+01
RA228	5.8E+00	3.E-08	2.5E-02	1.E-03	9.1E+09	4.4E-09	9.1E+06	2.5E+01
TH228	1.9E+00	7.E-06	1.5E-14	5.E-02	1.2E+08	5.7E+05	5.9E+06	3.0E-13
TH230	7.7E+04	2.E-06	1.5E-14	5.E-02	1.0E+04	6.6E+09	5.1E+02	3.0E-13
TH232	1.4E+10	2.E-06	1.5E-14	5.E-02	5.5E-02	1.2E+15	2.8E-03	3.0E-13
PA231	3.3E+04	9.E-07	1.0E+01	5.E-03	5.3E+04	1.9E-06	2.6E+02	2.0E+03
U 233	1.6E+05	3.E-05	9.5E-05	5.E-01	3.2E+02	3.2E+01	1.6E+02	1.9E-04
U 234	2.4E+05	3.E-05	9.5E-05	5.E-01	2.1E+02	5.0E+01	1.0E+02	1.9E-04
U 235	7.0E+08	3.E-05	9.5E-05	5.E-01	7.2E-02	1.5E+05	3.6E-02	1.9E-04
U 236	2.3E+07	3.E-05	9.5E-05	5.E-01	2.2E+00	4.9E+03	1.1E+00	1.9E-04
U 238	4.5E+09	4.E-05	9.5E-05	5.E-01	8.4E-03	1.3E+06	4.2E-03	1.9E-04
NP237	2.1E+06	3.E-06	5.0E+02	8.E-03	2.3E+02	8.5E-06	1.9E+00	6.3E+04
PU238	8.8E+01	5.E-06	3.0E-05	8.E-04	3.4E+06	9.7E-03	2.7E+03	3.7E-02
PU239	2.4E+04	5.E-06	3.0E-05	8.E-04	1.2E+04	2.7E+00	9.8E+00	3.7E-02
PU240	6.5E+03	5.E-06	3.0E-05	8.E-04	4.6E+04	7.3E-01	3.6E+01	3.7E-02
PU241	1.5E+01	2.E-04	3.0E-05	8.E-04	4.9E+05	6.7E-02	4.0E+02	3.7E-02
PU242	3.9E+05	5.E-06	3.0E-05	8.E-04	7.6E+02	4.4E+01	6.1E-01	3.7E-02
AM241	4.3E+02	4.E-06	4.0E+03	4.E-02	8.6E+05	2.9E+10	3.4E+04	1.0E+25
AM243	7.4E+03	4.E-06	4.0E+03	4.E+04	5.0E+04	5.0E-09	2.0E+09	1.0E-01
CM242	4.5E-01	2.E-05	4.0E+04	5.E-01	1.7E+08	1.5E-13	8.3E+07	8.0E+04
CM244	1.8E+01	7.E-06	4.0E+04	5.E-01	1.2E+07	2.1E-12	5.9E+06	8.0E+04
CM245	8.5E+03	4.E-06	4.0E+04	5.E-01	4.3E+04	5.8E-10	2.1E+04	8.0E+04
CM246	4.8E+03	4.E-06	4.0E+04	5.E-01	7.6E+04	3.3E-10	3.8E+04	8.0E+04

BBBBB - NO VALUE FOR RCG IN IOCFR20, USED BETA DEFAULT VALUE OF 3E-6 CI/L

TABLE 5. Radionuclides in High-Level Waste for Which Element Solubility in Ground Water Is Lower Than Radiological RCG from 10CFR20

NUCLIDE	HALF-LIFE	10CFR20 RCG	CHEMICAL SOLUBILITY	RADIO- TOXICITY	RCG/ CHEMSOL
	YR	CI/L	MG/L	M ³ /G	
ZR 93	9.5E+05	8.E-04	1.0E-25	5.1E+00	2.0E+24
RU106	1.0E+00	1.E-05	8.0E-16	3.3E+08	3.7E+06
PD107	6.5E+06	1.E-03	4.0E-17	5.1E-01	4.9E+16
SN126	1.0E+05	4.E-04	2.0E-26	7.1E+01	7.0E+23
TH228	1.9E+00	7.E-06	1.5E-14	1.2E+08	5.7E+05
TH230	7.7E+04	2.E-06	1.5E-14	1.0E+04	6.6E+09
TH232	1.4E+10	2.E-06	1.5E-14	5.5E-02	1.2E+15
U 233	1.6E+05	3.E-05	9.5E-05	3.2E+02	3.2E+01
U 234	2.4E+05	3.E-05	9.5E-05	2.1E+02	5.0E+01
U 235	7.0E+08	3.E-05	9.5E-05	7.2E-02	1.5E+05
U 236	2.3E+07	3.E-05	9.5E-05	2.2E+00	4.9E+03
U 238	4.5E+09	4.E-05	9.5E-05	8.4E-03	1.3E+06
PU239	2.4E+04	5.E-06	3.0E-05	1.2E+04	2.7E+00
PU242	3.9E+05	5.E-06	3.0E-05	7.6E+02	4.4E+01

* The chemical solubility of ruthenium is known to be far higher than this prediction from the solubility product of Ru(OH)₃.

TABLE 6. Radionuclides in High-Level Waste for Which Element Solubility in Ground Water Is in the Range 1 to 10,000 Times the RCG from 10CFR20

NUCLIDE	HALF-LIFE	10CFR20	CHEMICAL	RADIO-	RCG/
	YR	RCG	SOLUBILITY	TOXICITY	CHEMSOL
		CI/L	MG/L	M+3/G	
C 14	5.7E+03	8.E-04	6.0E-02	5.6E+03	3.0E-03
TC 99	2.1E+05	3.E-04	1.0E+02	5.7E+01	1.8E-04
SB125	2.7E+00	4.E-04	2.5E-06	2.6E+06	1.5E-01
H0166M	1.2E+03	5.E-02	5.0E+01	3.6E+01	5.6E-04
PU238	8.8E+01	5.E-06	3.0E-05	3.4E+06	9.7E-03
PU240	6.5E+03	5.E-06	3.0E-05	4.6E+04	7.3E-01
PU241	1.5E+01	2.E-04	3.0E-05	4.9E+05	6.7E-02

TABLE 7. Radionuclides in High-Level Waste for Which Radiotoxicity Is Less Than Chemical Toxicity

NUCLIDE	HALF-LIFE	10CFR20	CHEMICAL	RADIO-	RADTOX/
	YR	RCG*	MPL**	TOXICITY	CHEMTUX
		CI/L	MG/L	M+3/G	
PD107	6.5E+06	1.E-03	5.E-02	5.1E-01	2.6E-02
TH232	1.4E+10	2.E-06	5.E-02	5.5E-02	2.8E-03
U 235	7.0E+08	3.E-05	5.E-01	7.2E-02	3.6E-02
U 238	4.5E+09	4.E-05	5.E-01	8.4E-03	4.2E-03
PU242	3.9E+05	5.E-06	8.E-04	7.6E+02	6.1E-01

* Recommended Concentration Guide for Radionuclides in Drinking Water.

** Maximum Permissible Chemical Limit in Drinking Water.

TABLE 8. Radionuclides in High-Level Waste for
Which Radiotoxicity Is 1 to 10,000 Times Greater
Than the Chemical Toxicity

NUCLIDE	HALF-LIFE	10CFR20	CHEM	RADIO-	RADTOX/
	YR	RCG	MPL	TOXICITY	CHEMTOX
		CI/L	MG/L	M+3/G	
NI 59	8.0E+04	2.E-04	5.E-02	3.8E+02	1.9E+01
ZR 93	9.5E+05	8.E-04	1.E+00	5.1E+00	5.1E+00
MO 93	3.0E+03	BBBBBB	2.E-02	4.3E+05	8.5E+03
TC 99	2.1E+05	3.E-04	1.E+02	5.7E+01	5.7E+03
SN126	1.0E+05	4.E-04	5.E-02	7.1E+01	3.5E+00
CS135	2.3E+06	1.E-04	5.E+00	1.2E+01	5.8E+01
HO166M	1.2E+03	5.E-02	1.E+00	3.6E+01	3.6E+01
TH230	7.7E+04	2.E-06	5.E-02	1.0E+04	5.1E+02
PA231	3.3E+04	9.E-07	5.E-03	5.3E+04	2.6E+02
U 233	1.6E+05	3.E-05	5.E-01	3.2E+02	1.6E+02
U 234	2.4E+05	3.E-05	5.E-01	2.1E+02	1.0E+02
U 236	2.3E+07	3.E-05	5.E-01	2.2E+00	1.1E+00
NP237	2.1E+06	3.E-06	8.E-03	2.3E+02	1.9E+00
PU238	8.8E+01	5.E-06	8.E-04	3.4E+06	2.7E+03
PU239	2.4E+04	5.E-06	8.E-04	1.2E+04	9.8E+00
PU240	6.5E+03	5.E-06	8.E-04	4.6E+04	3.6E+01
PU241	1.5E+01	2.E-04	8.E-04	4.9E+05	4.0E+02

BBBBB - NO VALUE FOR RCG IN 10CFR20, USED BETA DEFAULT VALUE OF 3E-6 CI/L

APPENDIX A

METHODOLOGY FOR ESTIMATING SOLUBILITIES

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

APPENDIX A

NOTES ON THE BASIS BY WHICH SOLUBLE CONCENTRATIONS WERE SELECTED

The following notes describe the Basis methods by which soluble concentrations were selected. Numerical subnotes within each category reflect nuances employed in dealing with a specific element.

METHOD A

Method A was employed only when complete solubility data could be obtained for that element. The solubility was calculated for the element with each separate ion that was applicable, and the lowest one is listed as maximum solubility.

Subnotes to Method A

1. Solubility is based on the percentage of hydrogen in water.
2. Solubility is based on the percentage of deuterium, tritium in water, assuming that all hydrogen in water is deuterium, tritium.
3. Solubility is based on the percentage of oxygen in water.

METHOD B

Method B was employed only for the noble gases. The values given are the solubilities at 20°C and 1 atmosphere pressure. For deep burial the solubility could be corrected by using Henry's law, which states that the solubility is directly proportional to the absolute pressure.

METHOD C

Method C was used when complete solubility data for an element was lacking but enough data was there to eliminate one or more ions by periodicity, thermodynamic properties, or extreme insolubility of one ion whose data was available.

Subnotes to Method C

1. Beryllium carbonate was discounted by periodicity.
2. Aluminum carbonate was discounted because of the high insolubility of aluminum hydroxide.

3. Scandium carbonate, sulfate, nitrate, and chloride were discounted because of their relatively soluble properties compared with the insoluble scandium hydroxide.
4. Titanium carbonate, sulfate, nitrate, and chloride were discounted because of the extreme insolubility of titanium hydroxide.
5. Magnesium and calcium vanadate were discounted because of low solubility of vanadous acid.
6. Gallium carbonate, sulfate, nitrate, and chloride were discounted because of the low solubility of gallium hydroxide.
7. Yttrium carbonate was discounted because of thermodynamic properties. (See Reference 13).
8. Zirconium carbonate, sulfate, nitrate, and chloride were discounted because of the extreme insolubility of zirconium hydroxide.
9. Ruthenium carbonate, sulfate, nitrate, and chloride were discounted because of the extreme insolubility of ruthenium hydroxide.
10. Rhodium carbonate, sulfate, nitrate, and chloride were discounted because of the insolubility of rhodium hydroxide.
11. Palladium carbonate, sulfate, nitrate, and chloride were discounted because of the extreme insolubility of palladium hydroxide.
12. Indium carbonate discounted because of the low solubility of indium hydroxide.
13. Tin carbonate was discounted because of the extreme insolubility of tin hydroxide.
14. Antimony carbonate was discounted because of the low solubility of antimony hydroxide.
15. Potassium, magnesium, and calcium tellurate were discounted because of thermodynamic properties. (See Reference 13).
16. Lanthanide sulfates, carbonates, nitrates, and chlorides were discounted because lanthanum sulfate, nitrate, and chloride are more soluble than lanthanum hydroxide, and the lanthanides exhibit excellent periodicity.

17. Hafnium sulfate, carbonate, nitrate, and chloride were discounted because of lack of data.
18. Osmium sulfate, carbonate, and nitrate were discounted because lack of data.
19. Iridium carbonate was discounted because of lack of data; iridium sulfate and nitrate were discounted because of the low solubility of iridium oxide.
20. Platinum, gold, and thorium anions were discounted because of the extreme insolubility of hydroxides.
21. Bismuth carbonate was discounted because of lack of data.
22. Radium carbonate was discounted by periodicity.
23. Actinium carbonate, sulfate, nitrate, and chloride were discounted because of lack of data.
24. Uranyl carbonate was discounted by low uranyl hydroxide solubility.
25. Neptunyl carbonate, sulfate, nitrate, and chloride were discounted because of lack of data.
26. Americium and curium anions other than hydroxides were discounted because of lack of data.
27. Silicates were discounted because silica was found to be the most stable form at ground water temperature. (See Reference 13)
28. Plutonium was estimated from solubility of PuO_2 in a partial pressure of $10^{-3.5}$ atm CO_2 in Figure 8 of Reference 17.

METHOD D

Method D was devised to predict the solubility of technetium, rhenium, and tantalum. The values given were extrapolated with respect to periodic and thermodynamic properties.

METHOD E

Method E was devised to predict the solubilities of some of the lanthanides. The values were obtained by plotting the logarithms of the known values and then linearly interpolating the unknown values.

METHOD F

This method was derived to predict a value for polonium. The value was obtained by comparing thermodynamic data with other elements in the immediate vicinity. The most similar element was tellurium, the data indicating that it should be slightly less soluble than polonium.

METHOD G

Method G was employed to predict the solubilities of astatine and francium. Since every element in their group has about the same solubility, these same values were assigned to them.

METHOD H

Method H was devised to predict the solubility of protactinium. Because of lack of data and poor periodic and thermodynamic behavior, the value given is a very conservative educated guess.

APPENDIX B

COMPARISONS OF SOLUBILITIES IN GROUND WATER WITH RADIOTOXICITIES AND CHEMICAL TOXICITIES

Extended to Include All Radionuclides in the Periodic Table with Half-Lives Greater than 1 Year.

- Table B.1. Comparison of Element Solubility with Radiotoxicity and Chemical Toxicity.
- Table B.2. Radionuclides for Which Element Solubility Is Lower Than Radiological Recommended Guide from 10CFR20.
- Table B.3. Radionuclides for Which Element Solubility Is in the Range 1 to 10,000 Times RCG in 10CFR20.
- Table B.4. Radionuclides for Which Radiotoxicity Is Less Than Chemical Toxicity.
- Table B.5. Radionuclides for Which Radiotoxicity Is in the Range 1 to 10,000 Times RCG in 10CFR20.
- Table B.6. Radionuclides for Which Element Solubility in Ground Water Is less than Chemical Maximum Permissible Limit in Drinking Water.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

TABLE B.1. Comparison of Element Solubility with
Radiotoxicity and Chemical Toxicity for Selected
Radionuclides

ELSOL3 14:21 09/09/74

NUCLIDE	HALF-LIFE	10CFR20	CHEM	CHEM	RADTOX	RCG/	RADTOX/	CHEMSOL/
	YR	RCG	SOL	MPL		CHEMSOL	CHEMTOX	MPL
		CI/L	MG/L	MG/L	M+3/G			
H 3	1.2E+01	3.E-03	3.0E+05	3.E+05	3.2E+06	1.0E-12	9.7E+11	1.0E+00
BE 10	1.6E+06	BBBBBB	2.5E-10	1.E+00	7.5E+03	5.4E+05	7.5E+03	2.5E-10
C 14	5.7E+03	8.E-04	6.0E-02	4.E+02	5.6E+03	3.0E-03	2.2E+06	1.5E-04
NA 20	2.6E+00	4.E-05	1.0E+05	1.E+03	1.7E+08	5.8E-14	1.7E+11	1.0E+02
AL 26	7.3E+05	BBBBBB	4.0E-10	1.E-02	6.3E+03	4.0E+05	6.3E+01	4.0E-08
SI 32	2.8E+02	BBBBBB	5.6E+01	5.E+00	1.3E+07	1.3E-09	6.7E+07	1.1E+01
CL 36	3.0E+05	8.E-05	3.0E+05	1.E+02	4.1E+02	8.1E-09	5.2E+04	2.4E+03
AR 39	2.7E+02	BBBBBB	7.1E+01	2.E+03	1.1E+07	1.2E-09	2.0E+10	3.9E-02
K 40	1.3E+09	BBBBBB	4.0E+05	1.E+03	2.3E+00	1.1E-06	2.3E+03	4.0E+02
AR 42	3.3E+01	BBBBBB	7.1E+01	2.E+03	8.6E+07	1.6E-10	1.5E+11	3.9E-02
CA 41	1.3E+05	BBBBBB	5.4E+01	3.E+01	2.2E+04	8.3E-07	6.7E+05	1.8E+00
CA 45	4.5E-01	9.E-06	5.4E+01	3.E+01	2.0E+09	9.4E-12	5.9E+10	1.8E+00
TI 44	4.7E+01	BBBBBB	4.0E-17	1.E-01	5.8E+07	4.3E+08	5.8E+06	4.0E-16
V 49	9.1E-01	BBBBBB	1.5E-05	1.E-01	2.7E+09	2.5E-05	2.7E+08	1.5E-04
V 50	4.0E+16	BBBBBB	1.5E-05	1.E+03	6.0E-08	1.1E+12	6.0E-05	1.5E-08
MN 53	3.7E+06	BBBBBB	7.0E-01	1.E-02	6.1E+02	2.3E-03	6.1E+00	7.0E+01
MN 54	8.6E-01	1.E-04	7.0E-01	1.E-02	7.7E+07	1.8E-08	7.7E+05	7.0E+01
FE 55	2.7E+00	8.E-04	1.8E-09	5.E-02	3.0E+06	1.8E+02	1.5E+05	3.6E-08
FE 60	1.0E+05	BBBBBB	1.8E-09	5.E-02	2.0E+04	2.8E+04	9.9E+02	3.6E-08
C 57	7.4E-01	5.E-04	8.0E-03	5.E-02	1.7E+07	7.4E-06	8.5E+05	1.6E-01
CO 60	5.3E+00	5.E-05	8.0E-03	5.E-02	2.3E+07	5.5E-06	1.1E+06	1.6E-01
NI 59	8.0E+04	2.E-04	5.0E+01	5.E-02	3.8E+02	5.3E-05	1.9E+01	1.0E+03
NI 63	1.0E+02	3.E-05	5.0E+01	5.E-02	1.9E+06	1.1E-08	9.5E+04	1.0E+03
ZN 65	6.7E-01	1.E-04	1.0E+00	5.E-02	8.2E+07	1.2E-08	4.1E+06	2.0E+01
GE 68	7.9E-01	BBBBBB	6.0E+00	5.E-01	2.2E+09	7.5E-11	1.1E+09	1.2E+01
SE 79	6.5E+04	BBBBBB	2.4E+02	1.E-02	2.3E+04	1.8E-07	2.3E+02	2.4E+04
KR 81	2.1E+05	BBBBBB	3.0E+02	4.E+03	7.0E+03	4.8E-07	2.7E+07	7.9E-02
KR 85	1.1E+01	BBBBBB	3.0E+02	4.E+03	1.3E+08	2.5E-11	5.0E+11	7.9E-02
RB 87	4.7E+10	1.E-04	5.0E+05	5.E+00	8.8E-04	2.3E-03	4.4E-03	1.0E+05
Y 88	2.9E-01	BBBBBB	5.6E+01	1.E-03	4.6E+09	3.8E-12	4.6E+06	5.6E+04
SR 90	2.9E+01	3.E-07	1.1E+01	1.E+01	4.6E+08	2.0E-10	4.6E+09	1.1E+00
ZR 93	9.5E+05	8.E-04	1.0E-25	1.E+00	5.1E+00	2.0E+24	5.1E+00	1.0E-25
NB 92	2.0E+07	BBBBBB	8.7E+03	2.E-02	6.5E+01	1.8E-06	1.3E+00	4.3E+05
NB 93 M	1.2E+01	4.E-04	8.7E-03	2.E-02	8.0E+05	1.4E-04	1.6E+04	4.3E-01
NB 94	2.0E+04	BBBBBB	8.7E-03	2.E-02	6.3E+04	1.8E-03	1.3E+03	4.3E-01
MO 93	3.0E+03	BBBBBB	7.0E+02	2.E-02	4.3E+05	3.3E-09	8.5E+03	3.5E+04
TC 97	2.6E+06	2.E-03	1.0E+02	1.E+02	7.1E-01	1.4E-02	7.1E+01	1.0E+00
TC 98	1.5E+06	BBBBBB	1.0E+02	1.E+02	8.1E+02	1.2E-05	8.1E+04	1.0E+00
TC 99	2.1E+05	3.E-04	1.0E+02	1.E+02	5.7E+01	1.8E-04	5.7E+03	1.0E+00
RU106	1.0E+00	1.E-05	8.0E-16	1.E+00	3.3E+08	3.7E+06	3.3E+08	8.0E-16
RH101	3.0E+00	BBBBBB	8.0E-10	5.E-02	3.9E+08	3.2E+00	2.0E+07	1.6E-08
RH102	3.0E+00	BBBBBB	8.0E-10	5.E-02	3.9E+08	3.2E+00	1.9E+07	1.6E-08
RH102 M	5.7E-01	BBBBBB	8.0E-10	5.E-02	2.1E+09	6.1E-01	1.0E+08	1.6E-08
PD107	6.5E+06	1.E-03	4.0E-17	5.E-02	5.1E-01	4.9E+16	2.6E-02	8.0E-16
AG108	1.3E+02	BBBBBB	3.0E-02	1.E-03	8.5E+06	3.9E-06	8.5E+03	3.0E+01

TABLE B.1 (continued) Comparison of Element Solubility
with Radiotoxicity and Chemical Toxicity for Selected
Radionuclides

NUCLIDE	HALF-LIFE	10CFR20 RCG	CHEM SOL	CHEM MPL	RADTOX M13/G	RCG/ CHEMSOL	RADTOX/ CHEMTUX	CHEMSOL / MPL
	YR	CI/L	MG/L	MG/L				
AG110M	6.9E-01	3.E-05	3.0E-02	1.E-03	1.6E+08	2.1E-07	1.6E+05	3.0E+01
CD109	1.2E+00	2.E-04	4.0E-04	5.E-02	1.3E+07	1.9E-04	6.6E+05	8.0E-03
CD113	9.0E+15	BBBBBB	4.0E-04	1.E-02	1.2E-07	2.1E+10	1.2E-09	4.0E-02
CD113M	1.5E+01	BBBBBB	4.0E-04	5.E-02	7.2E+07	3.5E-05	3.6E+06	8.0E-03
IN115	5.0E+14	BBBBBB	5.0E-10	2.E-02	2.1E-06	9.6E+14	4.1E-08	2.5E-08
SN113	3.2E-01	8.E-05	2.0E-26	5.E-02	1.3E+08	4.0E+17	6.3E+06	4.0E-25
SN119M	6.7E-01	BBBBBB	2.0E-26	5.E-02	1.5E+09	3.3E+16	7.5E+07	4.0E-25
SN121M	5.0E+01	BBBBBB	2.0E-26	5.E-02	2.0E+07	2.5E+18	9.9E+05	4.0E-25
SN123	3.5E-01	BBBBBB	2.0E-26	5.E-02	2.7E+09	1.8E+16	1.4E+08	4.0E-25
SN126	1.0E+05	4.E-04	2.0E-26	5.E-02	7.1E+01	7.0E+23	3.5E+00	4.0E-25
SR125	2.7E+00	4.E-04	2.5E-06	5.E-02	2.6E+06	1.5E-01	1.3E+05	5.0E-05
TE121M	4.1E-01	BBBBBB	5.0E+00	2.E-01	2.4E+09	8.3E-11	4.8E+08	2.5E+01
TE123	1.2E-13	BBBBBB	5.0E+00	2.E-01	8.1E-05	2.5E+03	1.6E-05	2.5E+01
TE127M	3.0E-01	5.E-05	5.0E+00	2.E-01	1.9E+08	1.1E-09	3.8E+07	2.5E+01
I 129	1.6E+07	6.E-08	6.0E+05	1.E+01	2.9E+03	5.7E-10	2.9E+04	6.0E+04
CS134	2.1E+00	9.E-06	6.0E+05	5.E+00	1.4E+08	1.2E-14	7.2E+08	1.2E+05
CS135	2.3E+06	1.E-04	6.0E+05	5.E+00	1.2E+01	1.4E-07	5.8E+01	1.2E+05
CS137	3.0E+01	2.E-05	6.0E+05	5.E+00	4.3E+06	3.8E-13	2.2E+07	1.2E+05
BA133	1.0E+01	BBBBBB	4.0E-02	5.E-01	8.6E+07	2.9E-07	4.3E+07	8.0E-02
LA137	6.0E+04	BBBBBB	1.0E+04	1.E+00	1.5E+04	6.9E-09	1.5E+04	1.0E+04
LA138	1.1E+11	BBBBBB	1.0E+04	1.E+00	8.2E-03	1.2E-02	8.2E-03	1.0E+04
CE139	3.8E-01	BBBBBB	1.3E+04	2.E+00	2.3E+09	3.4E-14	4.6E+09	6.5E+03
CE142	5.0E+16	AAAAAA	1.3E+04	2.E+00	1.7E-06	4.6E+01	3.4E-06	6.5E+03
CE144	7.8E-01	1.E-05	1.3E+04	2.E+00	3.2E+08	2.4E-13	6.4E+08	6.5E+03
ND144	2.1E+15	AAAAAA	2.2E+03	2.E-01	3.9E-05	1.2E+01	7.9E-06	1.1E+04
PM143	7.3E-01	BBBBBB	1.2E+03	1.E+00	1.1E+09	7.3E-13	1.1E+09	1.2E+03
PM144	9.9E-01	BBBBBB	1.2E+03	1.E+00	8.3E+08	1.0E-12	8.3E+08	1.2E+03
PM145	1.8E+01	BBBBBB	1.2E+03	1.E+00	4.6E+07	1.8E-11	4.6E+07	1.2E+03
PM146	5.5E+00	BBBBBB	1.2E+03	1.E+00	1.5E+08	5.6E-12	1.5E+08	1.2E+03
PM147	2.6E+00	2.E-04	1.2E+03	1.E+00	4.6E+06	1.8E-10	4.6E+06	1.2E+03
SM145	9.3E-01	BBBBBB	8.1E+02	2.E-01	8.8E+08	1.4E-12	1.8E+08	4.1E+03
SM146	1.0E+08	AAAAAA	8.1E+02	2.E-01	8.2E+02	1.5E-06	1.6E+02	4.1E+03
SM147	1.1E+11	6.E-05	8.1E+02	2.E-01	3.8E-04	3.3E+00	7.6E-05	4.1E+03
SM148	8.0E+15	AAAAAA	8.1E+02	2.E-01	1.0E-05	1.2E+02	2.0E-06	4.1E+03
SM149	1.0E+16	AAAAAA	8.1E+02	2.E-01	8.0E-06	1.5E+02	1.6E-06	4.1E+03
SM151	9.3E+01	4.E-04	8.1E+02	2.E-01	6.4E+04	1.9E-08	1.3E+04	4.1E+03
EU150	3.5E+01	BBBBBB	4.1E+02	2.E-01	2.3E+07	1.1E-10	4.5E+06	2.0E+03
EU152	1.3E+01	8.E-05	4.1E+02	2.E-01	2.3E+06	1.1E-09	4.5E+05	2.0E+03
EU154	8.6E+00	2.E-05	4.1E+02	2.E-01	1.4E+07	1.8E-10	2.7E+06	2.0E+03
EU155	4.8E+00	2.E-04	4.1E+02	2.E-01	2.4E+06	1.0E-09	4.8E+05	2.0E+03
GD148	9.3E-01	AAAAAA	2.6E+02	2.E-01	8.7E+08	4.4E-12	1.7E+08	1.3E+03
GD150	1.8E+06	AAAAAA	2.6E+02	2.E-01	4.4E+04	8.7E-08	8.8E+03	1.3E+03
GD151	3.3E-01	BBBBBB	2.6E+02	2.E-01	2.4E+09	1.6E-12	4.8E+08	1.3E+03
GD152	1.1E+14	AAAAAA	2.6E+02	2.E-01	7.1E-04	5.4E+00	1.4E-04	1.3E+03
GD153	6.6E-01	2.E-04	2.6E+02	2.E-01	1.8E+07	2.2E-10	3.5E+06	1.3E+03
TB157	1.6E+02	BBBBBB	1.6E+02	5.E-01	4.7E+06	1.3E-09	2.4E+06	3.2E+02

TABLE B.1. (continued) Comparison of Element Solubility
with Radiotoxicity and Chemical Toxicity for Selected
Radionuclides

NUCLIDE	HALF-LIFE	IOCFR20	CHEM	CHEM	RADTOX	RCG/	RADTOX/	CHEMSOL/
	YR	RCG	SOL	MPL	Mt3/G	CHEMSOL	CHEMTUX	MPL
		CI/L	MG/L	MG/L				
TB158	1.5E+02	BBBBBB	1.6E+02	5.E-01	5.0E+06	1.2E-09	2.5E+06	3.2E+02
DY154	1.0E+06	AAAAAA	1.0E+02	1.E+00	7.7E+04	1.3E-07	7.7E+04	1.0E+02
DY156	2.0E+14	AAAAAA	1.0E+02	1.E+00	3.8E-04	2.6E+01	3.8E-04	1.0E+02
DY159	3.6E-01	BBBBBB	1.0E+02	1.E+00	2.1E+09	4.8E-12	2.1E+09	1.0E+02
H0163	3.3E+01	BBBBBB	5.0E+01	1.E+00	2.2E+07	9.0E-10	2.2E+07	5.0E+01
H0166M	1.2E+03	5.E-02	5.0E+01	1.E+00	3.6E+01	5.6E-04	3.6E+01	5.0E+01
TM170	3.5E-01	5.E-05	5.0E+00	2.E-01	1.2E+08	1.7E-09	2.4E+07	2.5E+01
TM171	1.9E+00	5.E-04	5.0E+00	2.E-01	2.2E+06	9.2E-08	4.4E+05	2.5E+01
LUI73	1.4E+00	BBBBBB	1.5E-01	1.E-01	5.0E+08	1.3E-08	5.0E+07	1.5E+00
LUI74M	4.3E-01	BBBBBB	1.5E-01	1.E-01	1.6E+09	4.2E-09	1.6E+08	1.5E+00
LUI74	3.6E+00	BBBBBB	1.5E-01	1.E-01	1.9E+08	3.5E-08	1.9E+07	1.5E+00
LUI76	2.7E+10	BBBBBB	1.5E-01	1.E-01	2.5E-02	2.7E+02	2.5E-03	1.5E+00
LUI77M	4.4E-01	1.E-04	1.5E-01	1.E-01	4.6E+07	1.5E-07	4.6E+06	1.5E+00
HF172	1.9E+00	BBBBBB	1.0E+05	5.E-02	3.7E+08	2.7E-14	1.9E+07	2.0E+06
HF174	2.0E+15	AAAAAA	1.0E+05	5.E-02	3.4E-05	2.9E-01	1.7E-06	2.0E+06
HF178M	3.0E+01	BBBBBB	1.0E+05	5.E-02	2.2E+07	4.5E-13	1.1E+06	2.0E+06
HF182	9.0E+06	BBBBBB	1.0E+05	5.E-02	7.3E+01	1.4E-07	3.6E+00	2.0E+06
TA179	1.6E+00	BBBBBB	1.0E+02	1.E+00	4.1E+08	2.5E-11	4.1E+08	1.0E+02
TA180	1.6E+13	BBBBBB	1.0E+02	1.E+00	4.1E-05	2.4E+02	4.1E-05	1.0E+02
TA182	3.2E-01	4.E-05	1.0E+02	1.E+00	1.6E+08	6.4E-11	1.6E+08	1.0E+02
W 181	3.3E-01	3.E-04	2.0E+00	1.E+02	2.0E+07	2.5E-08	2.0E+09	2.0E-02
RE184M	4.5E-01	BBBBBB	1.0E+02	5.E+01	1.4E+09	7.0E-12	7.2E+10	2.0E+00
RE187	5.0E+10	2.E-03	1.0E+02	1.E+01	1.9E-05	5.2E+02	1.9E-04	1.0E+01
US194	6.0E+00	BBBBBB	4.5E+04	1.E+00	1.0E+08	2.2E-13	1.0E+08	4.5E+04
IR192M	2.4E+02	4.E-05	2.0E+00	8.E-01	1.9E+05	2.6E-06	1.5E+05	2.5E+00
IR194M	4.7E-01	3.E-05	2.0E+00	8.E-01	1.3E+08	3.8E-09	1.1E+08	2.5E+00
PT190	7.0E+11	AAAAAA	8.0E-18	3.E-01	9.0E-02	1.4E+18	2.7E-02	2.7E-17
PT193	5.0E+01	1.E-03	8.0E-18	3.E-01	3.7E+04	3.4E+12	1.1E+04	2.7E-17
AU195	5.0E-01	BBBBBB	9.0E-22	2.E-02	1.2E+09	9.2E+11	2.4E+07	4.5E-20
HG194	1.3E+00	BBBBBB	1.4E-08	5.E-03	4.7E+08	1.5E-01	2.4E+06	2.8E-06
TL204	3.8E+00	6.E-05	4.0E+04	5.E-03	7.7E+06	3.2E-12	3.9E+04	8.0E+06
PB202	5.0E+05	BBBBBB	9.5E-04	1.E-02	1.2E+03	8.9E-01	1.2E+01	9.5E-02
PB204	1.4E+17	AAAAAA	9.5E-04	1.E-02	4.2E-07	2.5E+09	4.2E-09	9.5E-02
PB205	1.4E+07	BBBBBB	9.5E-04	1.E-02	4.2E+01	2.5E+01	4.2E-01	9.5E-02
PB210	2.2E+01	1.E-07	9.5E-04	1.E-02	7.6E+08	1.4E-06	7.6E+06	9.5E-02
BI207	3.8E+01	6.E-05	1.0E+00	1.E-01	7.6E+05	1.3E-06	7.6E+04	1.0E+01
BI208	3.7E+05	BBBBBB	1.0E+00	1.E-01	1.6E+03	6.4E-04	1.6E+02	1.0E+01
BI209	2.0E+19	AAAAAA	1.0E+00	1.E-01	2.9E-09	3.5E+08	2.9E-10	1.0E+01
BI210	3.5E+06	4.E-05	1.0E+00	1.E-01	1.2E+01	8.2E-02	1.2E+00	1.0E+01
P0208	2.9E+00	AAAAAA	1.0E+02	2.E-01	2.0E+10	5.1E-13	4.0E+09	5.0E+02
P0209	1.0E+02	AAAAAA	1.0E+02	2.E-01	5.6E+08	1.8E-11	1.1E+08	5.0E+02
P0210	3.8E-01	7.E-07	1.0E+02	2.E-01	6.4E+09	1.6E-12	1.3E+09	5.0E+02
RA226	1.6E+03	3.E-08	2.5E-02	1.E-03	3.3E+07	1.2E-06	3.3E+04	2.5E+01

TABLE B.1 (continued) Comparison of Element Solubility
with Radiotoxicity and Chemical Toxicity for Selected
Radionuclides

NUCLIDE	HALF-LIFE	10CFR20 RCG	CHEM SOL	CHEM MPL	RADTOX M+3/G	RCG/ CHEMSOL	RADTOX/ CHEMTUX	CHEMSOL/ MPL
	YR	CI/L	MG/L	MG/L				
RA228	5.8E+00	3.E-08	2.5E-02	1.E-03	9.1E+09	4.4E-09	9.1E+06	2.5E+01
AC227	2.2E+01	2.E-06	2.0E+05	1.E+00	3.6E+07	1.4E-13	3.6E+07	2.0E+05
TH228	1.9E+00	7.E-06	1.5E-14	5.E-02	1.2E+08	5.7E+05	5.9E+06	3.0E-13
TH229	7.3E+03	AAAAAA	1.5E-14	5.E-02	7.1E+06	9.4E+06	3.5E+05	3.0E-13
TH230	7.7E+04	2.E-06	1.5E-14	5.E-02	1.0E+04	6.6E+09	5.1E+02	3.0E-13
TH232	1.4E+10	2.E-06	1.5E-14	5.E-02	5.5E-02	1.2E+15	2.8E-03	3.0E-13
PA231	3.3E+04	9.E-07	1.0E+01	5.E-03	5.3E+04	1.9E-06	2.6E+02	2.0E+03
U 232	7.2E+01	3.E-05	9.5E-05	5.E-01	7.1E+05	1.5E-02	3.6E+05	1.9E-04
U 233	1.6E+05	3.E-05	9.5E-05	5.E-01	3.2E+02	3.2E+01	1.6E+02	1.9E-04
U 234	2.4E+05	3.E-05	9.5E-05	5.E-01	2.1E+02	5.0E+01	1.0E+02	1.9E-04
U 235	7.0E+08	3.E-05	9.5E-05	5.E-01	7.2E-02	1.5E+05	3.6E-02	1.9E-04
U 236	2.3E+07	3.E-05	9.5E-05	5.E-01	2.2E+00	4.9E+03	1.1E+00	1.9E-04
U 238	4.5E+09	4.E-05	9.5E-05	5.E-01	8.4E-03	1.3E+06	4.2E-03	1.9E-04
NP235	1.1E+00	AAAAAA	5.0E+02	8.E-03	4.7E+10	4.3E-14	3.7E+08	6.3E+04
NP236	1.3E+06	AAAAAA	5.0E+02	8.E-03	3.9E+04	5.1E-08	3.1E+02	6.3E+04
NP237	2.1E+06	3.E-06	5.0E+02	8.E-03	2.3E+02	8.5E-06	1.9E+00	6.3E+04
PU236	2.8E+00	AAAAAA	3.0E-05	8.E-04	1.8E+10	1.9E-06	1.4E+07	3.7E-02
PU238	8.8E+01	5.E-06	3.0E-05	8.E-04	3.4E+06	9.7E-03	2.7E+03	3.7E-02
PU239	2.4E+04	5.E-06	3.0E-05	8.E-04	1.2E+04	2.7E+00	9.8E+00	3.7E-02
PU240	6.5E+03	5.E-06	3.0E-05	8.E-04	4.6E+04	7.3E-01	3.6E+01	3.7E-02
PU241	1.5E+01	2.E-04	3.0E-05	8.E-04	4.9E+05	6.7E-02	4.0E+02	3.7E-02
PU242	3.9E+05	5.E-06	3.0E-05	8.E-04	7.6E+02	4.4E+01	6.1E-01	3.7E-02
PU244	8.3E+07	4.E-06	3.0E-05	8.E-04	4.4E+00	7.5E+03	3.5E-03	3.7E-02
AM241	4.3E+02	4.E-06	4.0E+03	4.E-02	8.6E+05	2.9E-10	3.4E+04	1.0E+05
AM242M	1.5E+02	4.E-06	4.0E+03	4.E-02	2.4E+06	1.0E-10	9.7E+04	1.0E+05
AM243	7.4E+03	4.E-06	4.0E+03	4.E-02	5.0E+04	5.0E-09	2.0E+03	1.0E+05
CM242	4.5E-01	2.E-05	4.0E+04	5.E-01	1.7E+08	1.5E-13	8.3E+07	8.0E+04
CM243	2.8E+01	5.E-06	4.0E+04	5.E-01	1.1E+07	2.4E-12	5.3E+06	8.0E+04
CM244	1.8E+01	7.E-06	4.0E+04	5.E-01	1.2E+07	2.1E-12	5.9E+06	8.0E+04
CM245	8.5E+03	4.E-06	4.0E+04	5.E-01	4.3E+04	5.8E-10	2.1E+04	8.0E+04
CM246	4.8E+03	4.E-06	4.0E+04	5.E-01	7.6E+04	3.3E-10	3.8E+04	8.0E+04
CM247	1.5E+07	4.E-06	4.0E+04	5.E-01	2.4E+01	1.1E-06	1.2E+01	8.0E+04
CM248	3.5E+05	4.E-07	4.0E+04	5.E-01	1.0E+04	2.4E-09	5.2E+03	8.0E+04
CM250	1.1E+04	AAAAAA	4.0E+04	5.E-01	4.2E+06	5.9E-12	2.1E+06	8.0E+04

AAAAA - NO VALUE FOR RCG IN 10CFR20, USED ALPHA DEFAULT VALUE OF 3E-8 CI/L
BBBBB - NO VALUE FOR RCG IN 10CFR20, USED BETA DEFAULT VALUE OF 3E-6 CI/L

TABLE B.2. Radionuclides for Which Element Solubility
Is Lower Than Radiological Recommended Guide from 10CFR20

ELS0L3 14:46 09/09/74

NUCLIDE	HALF-LIFE	10CFR20	CHEM	CHEM	RADTOX	RCG/	RADTOX/	CHEMSOL/
	YR	RCG	SOL	MPL		CHEMSOL	CHEMTOX	MPL
		CI/L	MG/L	MG/L	Mt3/G			
BE 10	1.6E+06	BBBBBB	2.5E-10	1.E+00	7.5E+03	5.4E+05	7.5E+03	2.5E-10
AL 26	7.3E+05	BBBBBB	4.0E-10	1.E-02	6.3E+03	4.0E+05	6.3E+01	4.0E-08
TI 44	4.7E+01	BBBBBB	4.0E-17	1.E-01	5.8E+07	4.3E+08	5.8E+06	4.0E-16
V 50	4.0E+16	BBBBBB	1.5E-05	1.E+03	6.0E-08	1.1E+12	6.0E-05	1.5E-08
FE 55	2.7E+00	8.E-04	1.8E-09	5.E-02	3.0E+06	1.8E+02	1.5E+05	3.6E-08
FE 60	1.0E+05	BBBBBB	1.8E-09	5.E-02	2.0E+04	2.8E+04	9.9E+02	3.6E-08
ZR 93	9.5E+05	8.E-04	1.0E-25	1.E+00	5.1E+00	2.0E+24	5.1E+00	1.0E-25
RU106	1.0E+00	1.E-05	8.0E-16	1.E+00	3.3E+08	3.7E+06	3.3E+08	8.0E-16
RH101	3.0E+00	BBBBBB	8.0E-10	5.E-02	3.9E+08	3.2E+00	2.0E+07	1.6E-08
RH102	3.0E+00	BBBBBB	8.0E-10	5.E-02	3.9E+08	3.2E+00	1.9E+07	1.6E-08
PD107	6.5E+06	1.E-03	4.0E-17	5.E-02	5.1E-01	4.9E+16	2.6E-02	8.0E-16
CD113	9.0E+15	BBBBBB	4.0E-04	1.E-02	1.2E-07	2.1E+10	1.2E-09	4.0E-02
IN115	5.0E+14	BBBBBB	5.0E-10	2.E-02	2.1E-06	9.6E+14	4.1E-08	2.5E-08
SN113	3.2E-01	8.E-05	2.0E-26	5.E-02	1.3E+08	4.0E+17	6.3E+06	4.0E-25
SN119M	6.7E-01	BBBBBB	2.0E-26	5.E-02	1.5E+09	3.3E+16	7.5E+07	4.0E-25
SN121M	5.0E+01	BBBBBB	2.0E-26	5.E-02	2.0E+07	2.5E+18	9.9E+05	4.0E-25
SN123	3.5E-01	BBBBBB	2.0E-26	5.E-02	2.7E+09	1.8E+16	1.4E+08	4.0E-25
SN126	1.0E+05	4.E-04	2.0E-26	5.E-02	7.1E+01	7.0E+23	3.5E+00	4.0E-25
TE123	1.2E+13	BBBBBB	5.0E+00	2.E-01	8.1E-05	2.5E+03	1.6E-05	2.5E+01
CE142	5.0E+16	AAAAAA	1.3E+04	2.E+00	1.7E-06	4.6E+01	3.4E-06	6.5E+03
ND144	2.1E+15	AAAAAA	2.2E+03	2.E-01	3.9E-05	1.2E+01	7.9E-06	1.1E+04
SM147	1.1E+11	6.E-05	8.1E+02	2.E-01	3.8E-04	3.3E+00	7.6E-05	4.1E+03
SM148	8.0E+15	AAAAAA	8.1E+02	2.E-01	1.0E-05	1.2E+02	2.0E-06	4.1E+03
SM149	1.0E+16	AAAAAA	8.1E+02	2.E-01	8.0E-06	1.5E+02	1.6E-06	4.1E+03
GD152	1.1E+14	AAAAAA	2.6E+02	2.E-01	7.1E-04	5.4E+00	1.4E-04	1.3E+03
DY156	2.0E+14	AAAAAA	1.0E+02	1.E+00	3.8E-04	2.6E+01	3.8E-04	1.0E+02
LU176	2.7E+10	BBBBBB	1.5E-01	1.E-01	2.5E-02	2.7E+02	2.5E-03	1.5E+00
TA180	1.6E+13	BBBBBB	1.0E+02	1.E+00	4.1E-05	2.4E+02	4.1E-05	1.0E+02
RE187	5.0E+10	2.E-03	1.0E+02	1.E+01	1.9E-05	5.2E+02	1.9E-04	1.0E+01
PT190	7.0E+11	AAAAAA	8.0E-18	3.E-01	9.0E-02	1.4E+18	2.7E-02	2.7E-17
PT193	5.0E+01	1.E-03	8.0E-18	3.E-01	3.7E+04	3.4E+12	1.1E+04	2.7E-17
AU195	5.0E-01	BBBBBB	9.0E-22	2.E-02	1.2E+09	9.2E+11	2.4E+07	4.5E-20
PB204	1.4E+17	AAAAAA	9.5E-04	1.E-02	4.2E-07	2.5E+09	4.2E-09	9.5E-02
PB205	1.4E+07	BBBBBB	9.5E-04	1.E-02	4.2E+01	2.5E+01	4.2E-01	9.5E-02
BI209	2.0E+19	AAAAAA	1.0E+00	1.E-01	2.9E-09	3.5E+08	2.9E-10	1.0E+01
TH228	1.9E+00	7.E-06	1.5E-14	5.E-02	1.2E+08	5.7E+05	5.9E+06	3.0E-13
TH229	7.3E+03	AAAAAA	1.5E-14	5.E-02	7.1E+06	9.4E+06	3.5E+05	3.0E-13
TH230	7.7E+04	2.E-06	1.5E-14	5.E-02	1.0E+04	6.6E+09	5.1E+02	3.0E-13
TH232	1.4E+10	2.E-06	1.5E-14	5.E-02	5.5E-02	1.2E+15	2.8E-03	3.0E-13
U 233	1.6E+05	3.E-05	9.5E-05	5.E-01	3.2E+02	3.2E+01	1.6E+02	1.9E-04
U 234	2.4E+05	3.E-05	9.5E-05	5.E-01	2.1E+02	5.0E+01	1.0E+02	1.9E-04
U 235	7.0E+08	3.E-05	9.5E-05	5.E-01	7.2E-02	1.5E+05	3.6E-02	1.9E-04
U 236	2.3E+07	3.E-05	9.5E-05	5.E-01	2.2E+00	4.9E+03	1.1E+00	1.9E-04
U 238	4.5E+09	4.E-05	9.5E-05	5.E-01	8.4E-03	1.3E+06	4.2E-03	1.9E-04
PU239	2.4E+04	5.E-06	3.0E-05	8.E-04	1.2E+04	2.7E+00	9.8E+00	3.7E-02

TABLE B.2 (continued) Radionuclides for Which Element
Solubility Is Lower Than Radiological Recommended Guide
from 10CFR20

NUCLIDE	HALF-LIFE	10CFR20	CHEM	CHEM	RADTOX	RCG/	RADTOX/	CHEMSOL/
		RCG	SOL	MPL		CHEMSOL	CHEMTOX	MPL
	YR	CI/L	MG/L	MG/L	M13/G			
PU242	3.9E+05	5.E-06	3.0E-05	8.E-04	7.6E+02	4.4E+01	6.1E-01	3.7E-02
PU244	8.3E+07	4.E-06	3.0E-05	8.E-04	4.4E+00	7.5E+03	3.5E-03	3.7E-02
AAAAA	-NO VALUE FOR RCG IN 10CFR20, USED ALPHA DEFAULT VALUE OF 3E-8 CI/L							
BBBBB	- NO VALUE FOR RCG IN 10CFR20, USED BETA DEFAULT VALUE OF 3E-6 CI/L							

TABLE B.3. Radionuclides for Which Element Solubility
Is in the Range 1 to 10,000 Times RCG in 10CFR20

ELSOL3 14:55 09/09/74

NUCLIDE	HALF-LIFE	10CFR20	CHEM	CHEM	RADTOX	RCG/	RADTOX/	CHEMSOL/
	YR	RCG	SOL	MPL		CHEMSOL	CHEMTOX	MPL
		CI/L	MG/L	MG/L	M+3/G			
C 14	5.7E+03	8.E-04	6.0E-02	4.E+02	5.6E+03	3.0E-03	2.2E+06	1.5E-04
MN 53	3.7E+06	BBBBBB	7.0E-01	1.E-02	6.1E+02	2.3E-03	6.1E+00	7.0E+01
RB 87	4.7E+10	1.E-04	5.0E+05	5.E+00	8.8E-04	2.3E-03	4.4E-03	1.0E+05
NB 93M	1.2E+01	4.E-04	8.7E-03	2.E-02	8.0E+05	1.4E-04	1.6E+04	4.3E-01
NB 94	2.0E+04	BBBBBB	8.7E-03	2.E-02	6.3E+04	1.8E-03	1.3E+03	4.3E-01
TC 97	2.6E+06	2.E-03	1.0E+02	1.E+02	7.1E-01	1.4E-02	7.1E+01	1.0E+00
TC 99	2.1E+05	3.E-04	1.0E+02	1.E+02	5.7E+01	1.8E-04	5.7E+03	1.0E+00
RH102M	5.7E-01	BBBBBB	8.0E-10	5.E-02	2.1E+09	6.1E-01	1.0E+08	1.6E-08
CD109	1.2E+00	2.E-04	4.0E-04	5.E-02	1.3E+07	1.9E-04	6.6E+05	8.0E-03
SB125	2.7E+00	4.E-04	2.5E-06	5.E-02	2.6E+06	1.5E-01	1.3E+05	5.0E-05
LA138	1.1E+11	BBBBBB	1.0E+04	1.E+00	8.2E-03	1.2E-02	8.2E-03	1.0E+04
HU166M	1.2E+03	5.E-02	5.0E+01	1.E+00	3.6E+01	5.6E-04	3.6E+01	5.0E+01
HF174	2.0E+15	AAAAAA	1.0E+05	5.E-02	3.4E-05	2.9E-01	1.7E-06	2.0E+06
HG194	1.3E+00	BBBBBB	1.4E-08	5.E-03	4.7E+08	1.5E-01	2.4E+06	2.8E-06
PB202	5.0E+05	BBBBBB	9.5E-04	1.E-02	1.2E+03	8.9E-01	1.2E+01	9.5E-02
BI208	3.7E+05	BBBBBB	1.0E+00	1.E-01	1.6E+03	6.4E-04	1.6E+02	1.0E+01
BI210	3.5E+06	4.E-05	1.0E+00	1.E-01	1.2E+01	8.2E-02	1.2E+00	1.0E+01
U 232	7.2E+01	3.E-05	9.5E-05	5.E-01	7.1E+05	1.5E-02	3.6E+05	1.9E-04
PU236	2.8E+00	AAAAAA	3.0E-05	8.E-04	1.8E+10	1.9E-06	1.4E+07	3.7E-02
PU238	8.8E+01	5.E-06	3.0E-05	8.E-04	3.4E+06	9.7E-03	2.7E+03	3.7E-02
PU240	6.5E+03	5.E-06	3.0E-05	8.E-04	4.6E+04	7.3E-01	3.6E+01	3.7E-02
PU241	1.5E+01	2.E-04	3.0E-05	8.E-04	4.9E+05	6.7E-02	4.0E+02	3.7E-02

AAAAA - NO VALUE FOR RCG IN 10CFR20, USED ALPHA DEFAULT VALUE OF 3E-8 CI/L
BBBBB - NO VALUE FOR RCG IN 10CFR20, USED BETA DEFAULT VALUE OF 3E-6 CI/L

TABLE B.4. Radionuclides for Which Radiotoxicity
Is Less Than Chemical Toxicity

ELSOL3 14:58 09/09/74

NUCLIDE	HALF-LIFE	10CFR20	CHEM	CHEM	RADTOX	RCG/	RADTOX/	CHEMSOL/
	YR	RCG	SOL	MPL	M+3/G	CHEMSOL	CHEMTUX	MPL
		CI/L	MG/L	MG/L				
V 50	4.0E+16	BBBBBB	1.5E-05	1.E+03	6.0E-08	1.1E+12	6.0E-05	1.5E-08
RB 87	4.7E+10	1.E-04	5.0E+05	5.E+00	8.8E-04	2.3E-03	4.4E-03	1.0E+05
PD107	6.5E+06	1.E-03	4.0E-17	5.E-02	5.1E-01	4.9E+16	2.6E-02	8.0E-16
CD113	9.0E+15	BBBBBB	4.0E-04	1.E-02	1.2E-07	2.1E+10	1.2E-09	4.0E-02
IN115	5.0E+14	BBBBBB	5.0E-10	2.E-02	2.1E-06	9.6E+14	4.1E-08	2.5E-08
TE123	1.2E+13	BBBBBB	5.0E+00	2.E-01	8.1E-05	2.5E+03	1.6E-05	2.5E+01
LA138	1.1E+11	BBBBBB	1.0E+04	1.E+00	8.2E-03	1.2E-02	8.2E-03	1.0E+04
CE142	5.0E+16	AAAAAA	1.3E+04	2.E+00	1.7E-06	4.6E+01	3.4E-06	6.5E+03
ND144	2.1E+15	AAAAAA	2.2E+03	2.E-01	3.9E-05	1.2E+01	7.9E-06	1.1E+04
SM147	1.1E+11	6.E-05	8.1E+02	2.E-01	3.8E-04	3.3E+00	7.6E-05	4.1E+03
SM148	8.0E+15	AAAAAA	8.1E+02	2.E-01	1.0E-05	1.2E+02	2.0E-06	4.1E+03
SM149	1.0E+16	AAAAAA	8.1E+02	2.E-01	8.0E-06	1.5E+02	1.6E-06	4.1E+03
GD152	1.1E+14	AAAAAA	2.6E+02	2.E-01	7.1E-04	5.4E+00	1.4E-04	1.3E+03
DY156	2.0E+14	AAAAAA	1.0E+02	1.E+00	3.8E-04	2.6E+01	3.8E-04	1.0E+02
LU176	2.7E+10	BBBBBB	1.5E-01	1.E-01	2.5E-02	2.7E+02	2.5E-03	1.5E+00
HF174	2.0E+15	AAAAAA	1.0E+05	5.E-02	3.4E-05	2.9E-01	1.7E-06	2.0E+06
TA180	1.6E+13	BBBBBB	1.0E+02	1.E+00	4.1E-05	2.4E+02	4.1E-05	1.0E+02
RE187	5.0E+10	2.E-03	1.0E+02	1.E+01	1.9E-05	5.2E+02	1.9E-04	1.0E+01
PT190	7.0E+11	AAAAAA	8.0E-18	3.E-01	9.0E-02	1.4E+18	2.7E-02	2.7E-17
PB204	1.4E+17	AAAAAA	9.5E-04	1.E-02	4.2E-07	2.5E+09	4.2E-09	9.5E-02
PB205	1.4E+07	BBBBBB	9.5E-04	1.E-02	4.2E+01	2.5E+01	4.2E-01	9.5E-02
BI209	2.0E+19	AAAAAA	1.0E+00	1.E-01	2.9E-09	3.5E+08	2.9E-10	1.0E+01
TH232	1.4E+10	2.E-06	1.5E-14	5.E-02	5.5E-02	1.2E+15	2.8E-03	3.0E-13
U 235	7.0E+08	3.E-05	9.5E-05	5.E-01	7.2E-02	1.5E+05	3.6E-02	1.9E-04
U 238	4.5E+09	4.E-05	9.5E-05	5.E-01	8.4E-03	1.3E+06	4.2E-03	1.9E-04
PU242	3.9E+05	5.E-06	3.0E-05	8.E-04	7.6E+02	4.4E+01	6.1E-01	3.7E-02
PU244	8.3E+07	4.E-06	3.0E-05	8.E-04	4.4E+00	7.5E+03	3.5E-03	3.7E-02

AAAAA - NO VALUE FOR RCG IN 10CFR20, USED ALPHA DEFAULT VALUE OF 3E-8 CI/L
BBBBB - NO VALUE FOR RCG IN 10CFR20, USED BETA DEFAULT VALUE OF 3E-6 CI/L

TABLE B.5. Radionuclides for Which Radiotoxicity
Is in the Range 1 to 10,000 Times RCG in 10CFR20

ELS0L3 15:03 09/09/74

NUCLIDE	HALF-LIFE	10CFR20	CHEM	CHEM	RADTOX	RCG/	RADTOX/	CHEMSOL/
	YR	RCG	SOL	MPL	Mt3/G	CHEMSOL	CHEMTOX	MPL
		CI/L	MG/L	MG/L				
BE 10	1.6E+06	BBBBBB	2.5E-10	1.E+00	7.5E+03	5.4E+05	7.5E+03	2.5E-10
AL 26	7.3E+05	BBBBBB	4.0E-10	1.E-02	6.3E+03	4.0E+05	6.3E+01	4.0E-08
K 40	1.3E+09	BBBBBB	4.0E+05	1.E+03	2.3E+00	1.1E-06	2.3E+03	4.0E+02
MN 53	3.7E+06	BBBBBB	7.0E-01	1.E-02	6.1E+02	2.3E-03	6.1E+00	7.0E+01
FE 60	1.0E+05	BBBBBB	1.8E-09	5.E-02	2.0E+04	2.8E+04	9.9E+02	3.6E-08
NI 59	8.0E+04	2.E-04	5.0E+01	5.E-02	3.8E+02	5.3E-05	1.9E+01	1.0E+03
SE 79	6.5E+04	BBBBBB	2.4E+02	1.E-02	2.3E+04	1.8E-07	2.3E+02	2.4E+04
ZR 93	9.5E+05	8.E-04	1.0E-25	1.E+00	5.1E+00	2.0E+24	5.1E+00	1.0E-25
NB 92	2.0E+07	BBBBBB	8.7E+03	2.E-02	6.5E+01	1.8E-06	1.3E+00	4.3E+05
NB 94	2.0E+04	BBBBBB	8.7E-03	2.E-02	6.3E+04	1.8E-03	1.3E+03	4.3E-01
MO 93	3.0E+03	BBBBBB	7.0E+02	2.E-02	4.3E+05	3.3E-09	8.5E+03	3.5E+04
TC 97	2.6E+06	2.E-03	1.0E+02	1.E+02	7.1E-01	1.4E-02	7.1E+01	1.0E+00
TC 99	2.1E+05	3.E-04	1.0E+02	1.E+02	5.7E+01	1.8E-04	5.7E+03	1.0E+00
AG108	1.3E+02	BBBBBB	3.0E-02	1.E-03	8.5E+06	3.9E-06	8.5E+03	3.0E+01
SN126	1.0E+05	4.E-04	2.0E-26	5.E-02	7.1E+01	7.0E+23	3.5E+00	4.0E-25
CS135	2.3E+06	1.E-04	6.0E+05	5.E+00	1.2E+01	1.4E-07	5.8E+01	1.2E+05
SM146	1.0E+08	AAAAAA	8.1E+02	2.E-01	8.2E+02	1.5E-06	1.6E+02	4.1E+03
GD150	1.8E+06	AAAAAA	2.6E+02	2.E-01	4.4E+04	8.7E-08	8.8E+03	1.3E+03
HO166M	1.2E+03	5.E-02	5.0E+01	1.E+00	3.6E+01	5.6E-04	3.6E+01	5.0E+01
HF182	9.0E+06	BBBBBB	1.0E+05	5.E-02	7.3E+01	1.4E-07	3.6E+00	2.0E+06
PR202	5.0E+05	BBBBBB	9.5E-04	1.E-02	1.2E+03	8.9E-01	1.2E+01	9.5E-02
BI208	3.7E+05	BBBBBB	1.0E+00	1.E-01	1.6E+03	6.4E-04	1.6E+02	1.0E+01
BI210	3.5E+06	4.E-05	1.0E+00	1.E-01	1.2E+01	8.2E-02	1.2E+00	1.0E+01
TH230	7.7E+04	2.E-06	1.5E-14	5.E-02	1.0E+04	6.6E+09	5.1E+02	3.0E-13
PA231	3.3E+04	9.E-07	1.0E+01	5.E-03	5.3E+04	1.9E-06	2.6E+02	2.0E+03
U 233	1.6E+05	3.E-05	9.5E-05	5.E-01	3.2E+02	3.2E+01	1.6E+02	1.9E-04
U 234	2.4E+05	3.E-05	9.5E-05	5.E-01	2.1E+02	5.0E+01	1.0E+02	1.9E-04
U 236	2.3E+07	3.E-05	9.5E-05	5.E-01	2.2E+00	4.9E+03	1.1E+00	1.9E-04
NP236	1.3E+06	AAAAAA	5.0E+02	8.E-03	3.9E+04	5.1E-08	3.1E+02	6.3E+04
NP237	2.1E+06	3.E-06	5.0E+02	8.E-03	2.3E+02	8.5E-06	1.9E+00	6.3E+04
PI238	8.8E+01	5.E-06	3.0E-05	8.E-04	3.4E+06	9.7E-03	2.7E+03	3.7E-02
PU239	2.4E+04	5.E-06	3.0E-05	8.E-04	1.2E+04	2.7E+00	9.8E+00	3.7E-02
PI240	6.5E+03	5.E-06	3.0E-05	8.E-04	4.6E+04	7.3E-01	3.6E+01	3.7E-02
PU241	1.5E+01	2.E-04	3.0E-05	8.E-04	4.9E+05	6.7E-02	4.0E+02	3.7E-02
AM243	7.4E+03	4.E-06	4.0E+03	4.E-02	5.0E+04	5.0E-09	2.0E+03	1.0E+05
CM247	1.5E+07	4.E-06	4.0E+04	5.E-01	2.4E+01	1.1E-06	1.2E+01	8.0E+04
CM248	3.5E+05	4.E-07	4.0E+04	5.E-01	1.0E+04	2.4E-09	5.2E+03	8.0E+04

AAAAA - NO VALUE FOR RCG IN 10CFR20, USED ALPHA DEFAULT VALUE OF 3E-8 CI/L
BBBBB - NO VALUE FOR RCG IN 10CFR20, USED BETA DEFAULT VALUE OF 3E-6 CI/L

TABLE B.6. Radionuclides for Which Element Solubility
in Ground Water Is Less Than Chemical Maximum Permissible
Limit in Drinking Water

ELS0L3 15:09 09/09/74

NUCLIDE	HALF-LIFE	IOCFR20	CHEM	CHEM	RADTOX	RCG/	RADTOX/	CHEMSOL/
	YR	RCG	SOL	MPL	M13/G	CHEMSOL	CHEMTOX	MPL
		CI/L	MG/L	MG/L				
BE 10	1.6E+06	BBBBBB	2.5E-10	1.E+00	7.5E+03	5.4E+05	7.5E+03	2.5E-10
C 14	5.7E+03	8.E-04	6.0E-02	4.E+02	5.6E+03	3.0E-03	2.2E+06	1.5E-04
AL 26	7.3E+05	BBBBBB	4.0E-10	1.E-02	6.3E+03	4.0E+05	6.3E+01	4.0E-08
AR 39	2.7E+02	BBBBBB	7.1E+01	2.E+03	1.1E+07	1.2E-09	2.0E+10	3.9E-02
AR 42	3.3E+01	BBBBBB	7.1E+01	2.E+03	8.6E+07	1.6E-10	1.5E+11	3.9E-02
TI 44	4.7E+01	BBBBBB	4.0E-17	1.E-01	5.8E+07	4.3E+08	5.8E+06	4.0E-16
V 49	9.1E-01	BBBBBB	1.5E-05	1.E-01	2.7E+09	2.5E-05	2.7E+08	1.5E-04
V 50	4.0E+16	BBBBBB	1.5E-05	1.E+03	6.0E-08	1.1E+12	6.0E-05	1.5E-08
FE 55	2.7E+00	8.E-04	1.8E-09	5.E-02	3.0E+06	1.8E+02	1.5E+05	3.6E-08
FE 60	1.0E+05	BBBBBB	1.8E-09	5.E-02	2.0E+04	2.8E+04	9.9E+02	3.6E-08
C 57	7.4E-01	5.E-04	8.0E-03	5.E-02	1.7E+07	7.4E-06	8.5E+05	1.6E-01
CU 60	5.3E+00	5.E-05	8.0E-03	5.E-02	2.3E+07	5.5E-06	1.1E+06	1.6E-01
KR 81	2.1E+05	BBBBBB	3.0E+02	4.E+03	7.0E+03	4.8E-07	2.7E+07	7.9E-02
KR 85	1.1E+01	BBBBBB	3.0E+02	4.E+03	1.3E+08	2.5E-11	5.0E+11	7.9E-02
ZR 93	9.5E+05	8.E-04	1.0E-25	1.E+00	5.1E+00	2.0E+24	5.1E+00	1.0E-25
NB 93M	1.2E+01	4.E-04	8.7E-03	2.E-02	8.0E+05	1.4E-04	1.6E+04	4.3E-01
NB 94	2.0E+04	BBBBBB	8.7E-03	2.E-02	6.3E+04	1.8E-03	1.3E+03	4.3E-01
RU106	1.0E+00	1.E-05	8.0E-16	1.E+00	3.3E+08	3.7E+06	3.3E+08	8.0E-16
RH101	3.0E+00	BBBBBB	8.0E-10	5.E-02	3.9E+08	3.2E+00	2.0E+07	1.6E-08
RH102	3.0E+00	BBBBBB	8.0E-10	5.E-02	3.9E+08	3.2E+00	1.9E+07	1.6E-08
RH102M	5.7E-01	BBBBBB	8.0E-10	5.E-02	2.1E+09	6.1E-01	1.0E+08	1.6E-08
PD107	6.5E+06	1.E-03	4.0E-17	5.E-02	5.1E-01	4.9E+16	2.6E-02	8.0E-16
CD109	1.2E+00	2.E-04	4.0E-04	5.E-02	1.3E+07	1.9E-04	6.6E+05	8.0E-03
CD113	9.0E+15	BBBBBB	4.0E-04	1.E-02	1.2E-07	2.1E+10	1.2E-09	4.0E-02
CD113M	1.5E+01	BBBBBB	4.0E-04	5.E-02	7.2E+07	3.5E-05	3.6E+06	8.0E-03
IN115	5.0E+14	BBBBBB	5.0E-10	2.E-02	2.1E-06	9.6E+14	4.1E-08	2.5E-08
SN113	3.2E-01	8.E-05	2.0E-26	5.E-02	1.3E+08	4.0E+17	6.3E+06	4.0E-25
SN119M	6.7E-01	BBBBBB	2.0E-26	5.E-02	1.5E+09	3.3E+16	7.5E+07	4.0E-25
SN121M	5.0E+01	BBBBBB	2.0E-26	5.E-02	2.0E+07	2.5E+18	9.9E+05	4.0E-25
SN123	3.5E-01	BBBBBB	2.0E-26	5.E-02	2.7E+09	1.8E+16	1.4E+08	4.0E-25
SN126	1.0E+05	4.E-04	2.0E-26	5.E-02	7.1E+01	7.0E+23	3.5E+00	4.0E-25
SB125	2.7E+00	4.E-04	2.5E-06	5.E-02	2.6E+06	1.5E-01	1.3E+05	5.0E-05
BA133	1.0E+01	BBBBBB	4.0E-02	5.E-01	8.6E+07	2.9E-07	4.3E+07	8.0E-02
W 181	3.3E-01	3.E-04	2.0E+00	1.E+02	2.0E+07	2.5E-08	2.0E+09	2.0E-02
PT190	7.0E+11	AAAAAA	8.0E-18	3.E-01	9.0E-02	1.4E+18	2.7E-02	2.7E-17
PT193	5.0E+01	1.E-03	8.0E-18	3.E-01	3.7E+04	3.4E+12	1.1E+04	2.7E-17
AU195	5.0E-01	BBBBBB	9.0E-22	2.E-02	1.2E+09	9.2E+11	2.4E+07	4.5E-20
HG194	1.3E+00	BBBBBB	1.4E-08	5.E-03	4.7E+08	1.5E-01	2.4E+06	2.8E-06
PB202	5.0E+05	BBBBBB	9.5E-04	1.E-02	1.2E+03	8.9E-01	1.2E+01	9.5E-02
PB204	1.4E+17	AAAAAA	9.5E-04	1.E-02	4.2E-07	2.5E+09	4.2E-09	9.5E-02
PB205	1.4E+07	BBBBBB	9.5E-04	1.E-02	4.2E+01	2.5E+01	4.2E-01	9.5E-02
PB210	2.2E+01	1.E-07	9.5E-04	1.E-02	7.6E+08	1.4E-06	7.6E+06	9.5E-02
TH228	1.9E+00	7.E-06	1.5E-14	5.E-02	1.2E+08	5.7E+05	5.9E+06	3.0E-13
TH229	7.3E+03	AAAAAA	1.5E-14	5.E-02	7.1E+06	9.4E+06	3.5E+05	3.0E-13

TABLE B.6 (continued) Radionuclides for Which Element
Solubility in Ground Water Is Less Than Chemical Maximum
Permissible Limit in Drinking Water

NUCLIDE	HALF-LIFE	10CFR20	CHEM	CHEM	RADTUX	RCG/	RADTUX/	CHEMSOL/
	YR	RCG	SOL	MPL		CHEMSOL	CHEMTUX	MPL
		CI/L	MG/L	MG/L	Mt3/G			
TH230	7.7E+04	2.E-06	1.5E-14	5.E-02	1.0E+04	6.6E+09	5.1E+02	3.0E-13
TH232	1.4E+10	2.E-06	1.5E-14	5.E-02	5.5E-02	1.2E+15	2.8E-03	3.0E-13
U 232	7.2E+01	3.E-05	9.5E-05	5.E-01	7.1E+05	1.5E-02	3.6E+05	1.9E-04
U 233	1.6E+05	3.E-05	9.5E-05	5.E-01	3.2E+02	3.2E+01	1.6E+02	1.9E-04
U 234	2.4E+05	3.E-05	9.5E-05	5.E-01	2.1E+02	5.0E+01	1.0E+02	1.9E-04
U 235	7.0E+08	3.E-05	9.5E-05	5.E-01	7.2E-02	1.5E+05	3.6E-02	1.9E-04
U 236	2.3E+07	3.E-05	9.5E-05	5.E-01	2.2E+00	4.9E+03	1.1E+00	1.9E-04
U 238	4.5E+09	4.E-05	9.5E-05	5.E-01	8.4E-03	1.3E+06	4.2E-03	1.9E-04
PU236	2.8E+00	AAAAA	3.0E-05	8.E-04	1.8E+10	1.9E-06	1.4E+07	3.7E-02
PU238	8.8E+01	5.E-06	3.0E-05	8.E-04	3.4E+06	9.7E-03	2.7E+03	3.7E-02
PU239	2.4E+04	5.E-06	3.0E-05	8.E-04	1.2E+04	2.7E+00	9.8E+00	3.7E-02
PU240	6.5E+03	5.E-06	3.0E-05	8.E-04	4.6E+04	7.3E-01	3.6E+01	3.7E-02
PU241	1.5E+01	2.E-04	3.0E-05	8.E-04	4.9E+05	6.7E-02	4.0E+02	3.7E-02
PU242	3.9E+05	5.E-06	3.0E-05	8.E-04	7.6E+02	4.4E+01	6.1E-01	3.7E-02
PU244	8.3E+07	4.E-06	3.0E-05	8.E-04	4.4E+00	7.5E+03	3.5E-03	3.7E-02

AAAAA - NO VALUE FOR RCG IN 10CFR20, USED ALPHA DEFAULT VALUE OF 3E-8 CI/L

BBBBB - NO VALUE FOR RCG IN 10CFR20, USED BETA DEFAULT VALUE OF 3E-6 CI/L

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

APPENDIX C

BASIC LANGUAGE COMPUTER PROGRAMS

AND FILES FOR UNIVAC 1108

- Table C.1. ELSOL3. Program for Comparison of Element Solubilities with Chemical and Radiological Toxicities.
- Table C.2. DATOX2. Abridged Data File of Chemical Maximum Permissible Limits in Potable Water for Radionuclides in High-Level Waste.
- Table C.3. DASOL2. Abridged Data File of Solubilities of Elements for Radionuclides in High-Level Waste.
- Table C.4. DATOX3. Unabridged Data File of Chemical Maximum Permissible Limits in Potable Water for Radionuclides in the Periodic Table with Half-Life Greater than One-Year.
- Table C.5. DASOL3. Unabridged Data File of Solubilities of Elements for Radionuclides in the Periodic Table with Half-Life Greater than One Year.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

TABLE C.1. Program for Comparison of Element
Solubilities with Chemical and Radiological
Toxicities

ELSOL3 15:18 09/09/74

```

40 PRINT USING 50
41 PRINT USING 51
45 PRINT
50 :   COMPARISON OF ELEMENT SOLUBILITY WITH RADIOTOXICITY
51 :   AND CHEMICAL TOXICITY FOR SELECTED RADIONUCLIDES
100 PRINT USING 110
110 :   NUCLIDE HALF-LIFE 10CFR20 CHEM  CHEM  RADTOX  RCG/  RADTOX/  MP
L/
120 PRINT USING 130
130 :           @  RCG  SOL  MPL  CHEMSOL  CHEMTOX  CHEM
SOL
140 PRINT USING 150
150 :           YR  CI/L  MG/L  MG/L  M+3/G
160 PRINT
170 FOR J=1 TO 200
173 IF END#0 GO TO 10000
175 READ A,A$,B,E,B$,F
180 READ A,A$,B,C,B$,D
190 IF B=9999 GO TO 210
200 GO TO 220
210 B=3E-6
220 IF B=8888 GO TO 240
230 GO TO 250
240 B=3E-8
250 CONTINUE
260 IF A$(2,1)="0" GO TO 280
270 GO TO 290
280 A$(2,1)=" "
290 IF A$(3,1)="0" GO TO 310
300 GO TO 320
310 A$(3,1)=" "
320 IF A$(3,1)=" " AND A$(4,1)="0" GO TO 340
330 GO TO 350
340 A$(4,1)=" "
350 C1=1/C
360 C2=1/D
362 C3=1/E
363 C4=1/F
370 IF B$(2,1)="0" GO TO 390
380 GO TO 400
390 B$(2,1)=" "
400 IF B$(3,1)="0" GO TO 420
410 GO TO 430
420 B$(3,1)=" "
430 IF B$(3,1)=" " AND B$(4,1)="0" GO TO 450
440 GO TO 460
450 B$(4,1)=" "
460 M1=VAL(A$(3,3))
470 R1=1/A/B/M1*LOG(2)*6.023E23/365/24/3600/3.7E10
480 R2=C1/R1
490 R3=R1/C3
500 R4=C3/C1
535 IF B=3E-6 OR B=3E-8 GO TO 592

```

TABLE C.1 (continued) Program for Comparison of Element
Solubilities with Chemical and Radiological Toxicities

```

540 CONTINUE
550 PRINT USING 560,A$,A,B,C,E,R1,R2,R3,R4
560 : ##### #.#!!!! #.!!!! #.#!!!! #.!!!! #.#!!!! #.#!!!! #.#
!!!!
570 GO T0600
580 PRINT USING 590,A$,A,B,C,E,R1,R2,R3,R4
590 : ##### ###.#!!!! #.#!!!! #.!!!! #.#!!!! #.#!!!! #.#!!!! #
###.#
591 GO T0600
592 IF B=3E-6 GO T0596
593 J$="AAAAAA"
594 PRINT USING 599,A$,A,J$,C,E,R1,R2,R3,R4
595 GO T0600
596 J$="BBBBBB"
597 PRINT USING 599,A$,A,J$,C,E,R1,R2,R3,R4
599 : ##### #.#!!!! #.!!!! #.#!!!! #.!!!! #.#!!!! #.#!!!! #.#
!!!!
600 NEXT J
610 CONTINUE
1999 DATA 12.33,H0003,3E-3,3E5,HE003,180
2000 DATA 12.33,H0003,3E-3,300000,HE003,2
10000 CONTINUE
10005 PRINT
10100 PRINT "AAAAA - NO VALUE FOR RCG IN 10CFR20,USED ALPHA DEFAULT VALUE
OF 3E-8 CI/L"
10200 PRINT "BBBBB - NO VALUE FOR RCG IN 10CFR20,USED BETA DEFAULT VALUE
OF 3E-6 CI/L"

```

TABLE C.2 Abridged Data File of Chemical Maximum Permissible
Limits in Potable Water for Radionuclides in High-Level Waste

DAT0X2 15:21 09/09/74

1999 DATA 12.33,H0003,3E-3,3E5,HE003,180
2009 DATA 5730,C0014,8E-4,400,N0014,2
2019 DATA 5.27,C0060,5E-5,.05,N1060,.05
2029 DATA 8E4,N1059,2E-4,.05,C0059,.05
2039 DATA 100,N1063,3E-5,.05,CU063,.2
2049 DATA 29,SR090,3E-7,10,ZR090,1.
2059 DATA 9.5E5,ZR093,8E-4,1,NB093,.02
2069 DATA 3E3,M0093,9999,.02,NB093,.02
2079 DATA 213000,TC099,3E-4,100,RU099,1
2089 DATA 1.011,RU106,1E-5,1,PD106,.05
2099 DATA 6.5E6,PD107,1E-3,.05,AG107,.001
2109 DATA 1E5,SN126,4E-4,.05,TE126,.2
2119 DATA 2.73,SR125,4E-4,.05,TE125,.2
2129 DATA 15.9E6,I0129,6E-8,10,XE129,5900
2139 DATA 2.06,CS134,9E-6,5,RA134,.5
2149 DATA 2.3E6,CS135,1E-4,5,RA135,.5
2159 DATA 30.1,CS137,2E-5,5,RA137,.5
2169 DATA .779,CE144,1E-5,2,ND144,.2
2179 DATA 2.6234,PM147,2E-4,1,SM147,.2
2189 DATA 13,EU152,8E-5,.2,SM152,.2
2199 DATA 8.6,EU154,2E-5,.2,GD154,.2
2209 DATA 4.8,EU155,2E-4,.2,GD155,.2
2219 DATA 1200,H0166M,5E-2,1,ER166,.1
2229 DATA 22.3,PB210,1E-7,0.01,PB206,0.01
2239 DATA 1600,RA226,3.01E-8,1E-3,PB206,0.01
2249 DATA 5.75,RA228,3.01E-8,1E-3,PB208,0.01
2259 DATA 1.913,TH228,7E-6,0.05,PB208,0.01
2269 DATA 7.7E4,TH230,2E-6,0.05,PB206,0.01
2279 DATA 1.4E10,TH232,2E-6,0.05,PB208,0.01
2289 DATA 3.25E4,PA231,9E-7,5E-3,PB207,0.01
2299 DATA 1.58E5,U0233,3E-5,0.5,BI209,0.1
2309 DATA 2.44E5,U0234,3E-5,0.5,BI209,0.1
2319 DATA 7.04E8,U0235,3E-5,0.5,PB207,0.01
2329 DATA 2.342E7,U0236,3E-5,0.5,TH232,0.05
2339 DATA 4.47E9,U0238,4E-5,0.5,PB206,0.01
2349 DATA 2.14E6,NP237,3.01E-6,8E-3,BI209,0.1
2359 DATA 87.8,PU238,5E-6,8E-4,U0234,0.5
2369 DATA 24390,PU239,5E-6,8E-4,U0235,0.5
2379 DATA 6540,PU240,5E-6,8E-4,U0236,0.5
2389 DATA 15,PU241,2E-4,8E-4,NP237,2E-5
2399 DATA 3.87E5,PU242,5E-6,8E-4,U0238,0.5
2409 DATA 433,AM241,4E-6,4E-2,NP237,8E-4
2419 DATA 0.446,CM242,8E-3,40000,U0238,9.5E-5
2429 DATA 28,CM243,5E-6,0.5,U0235,0.5
2439 DATA 17.9,CM244,7E-6,0.5,U236,0.5
2449 DATA 8500,CM245,4E-6,0.5,NP237,2E-5
2459 DATA 4760,CM246,4E-6,0.5,U0238,0.5

TABLE C.3. Abridged Data File of Solubilities of
Elements for Radionuclides in High-Level Waste

DAS0L2 15:25 09/09/74

2000 DATA 12.33,H0003,3E-3,300000,HE003,2
2010 DATA 5730,C0014,8E-4,6E-2,N0014,1E+5
2020 DATA 5.27,C0060,5E-5,8E-3,NI060,50
2030 DATA 8E4,NI059,2E-4,50,C0059,8E-3
2040 DATA 100,NI063,3E-5,50,CU063,1.4E-2
2050 DATA 29,SR090,3E-7,11,ZR090,1E-25
2060 DATA 9.5E5,ZR093,8E-4,1E-25,NB093,8.7E-3
2070 DATA 3E3,M0093,9999,700,NB093,8.7E-3
2080 DATA 213000,TC099,3E-4,100,RU099,8E-16
2090 DATA 1.011,RU106,1E-5,8E-16,PD106,4E-17
2100 DATA 6.5E6,PD107,1E-3,4E-17,AG107,0.03
2110 DATA 1E5,SN126,4E-4,2E-26,WTE126,5
2120 DATA 2.73,SB125,4E-4,2.5E-6,TE125,5
2130 DATA 15.9E6,I0129,6E-8,6E5,XE129,1000
2140 DATA 2.06,CS134,9E-6,6E5,BA134,0.04
2150 DATA 2.3E6,CS135,1E-4,6E5,BA135,0.04
2160 DATA 30.1,CS137,2E-5,6E5,BA137,0.04
2170 DATA .779,CE144,1E-5,1.3E4,ND144,2200
2180 DATA 2.6234,PM147,2E-4,1200,SM147,810
2190 DATA 13,EUI52,8E-5,410,SM152,810
2200 DATA 8.6,EUI54,2E-5,410,GDI54,260
2210 DATA 4.8,EUI55,2E-4,410,GDI55,260.
2220 DATA 1200,H0166M,5E-2,50,ERI66,20
2230 DATA 22.3,PB210,1E-7,9.5E-4,PB206,9.5E-4
2240 DATA 1600,RA226,3.01E-8,0.025,PB206,9.5E-4
2250 DATA 5.75,RA228,3.01E-8,0.025,PB208,9.5E-4
2260 DATA 1.913,TH228,7E-6,1.5E-14,PB208,9.5E-4
2270 DATA 7.7E4,TH230,2E-6,1.5E-14,PB206,9.5E-4
2280 DATA 1.4E10,TH232,2E-6,1.5E-14,PB208,9.5E-4
2290 DATA 3.25E4,PA231,9E-7,10,PB207,9.5E-4
2300 DATA 1.58E5,U0233,3E-5,9.5E-5,BI209,1
2310 DATA 2.44E5,U0234,3E-5,9.5E-5,BI209,1
2320 DATA 7.04E8,U0235,3E-5,9.5E-5,PB207,9.5E-4
2330 DATA 2.342E7,U0236,3E-5,9.5E-5,TH232,1.5E-14
2340 DATA 4.47E9,U0238,4E-5,9.5E-5,PB206,9.5E-4
2350 DATA 2.14E6,NP237,3.01E-6,500,BI209,1
2360 DATA 87.8,PU238,5E-6,3E-25,U0234,9.5E-5
2370 DATA 24390,PU239,5E-6,3E-25,U0235,9.5E-5
2380 DATA 6540,PU240,5E-6,3E-25,U0236,9.5E-5
2390 DATA 15,PU241,2E-4,3E-25,NP237,500.
2400 DATA 3.87E5,PU242,5E-6,3E-25,U0238,9.5E-5
2410 DATA 433,AM241,4E-6,4000,NP237,500
2420 DATA 7370,AM243,4E-6,4000,U0235,9.5E-5
2430 DATA 0.446,CM242,2E-5,40000,U0238,9.5E-5
2440 DATA 17.9,CM244,7E-6,40000,U0236,9.5E-5
2450 DATA 8500,CM245,4E-6,40000,NP237,500
2460 DATA 4760,CM246,4E-6,40000,U0238,9.5E-5

TABLE C.4. Unabridged Data File of Chemical Maximum Permissible Limits in Potable Water for Radionuclides in the Periodic Table Half-Life Greater Than One Year

DAT0X3 15:28 09/09/74

```

1999 DATA 12.33,H0003,3E-3,3E+5,HE003,180
2009 DATA 1.6E6,BE010,9999,1.0,R0010,1.0
2019 DATA 5730,C0014,8E-4,400,N0014,2
2029 DATA 2.601,NA020,4E-5,1000,NE022,900
2039 DATA 7.3E5,AL026,9999,0.01,MG026,10
2049 DATA 280,SI032,9999,5,S0032,50
2059 DATA 3.01E5,CL036,8E-5,125,AR036,1800
2069 DATA 269,AR039,9999,1800,K0039,1000
2079 DATA 1.28E9,K0040,9999,1000,CA040,30
2089 DATA 33,AR042,9999,1800,CA042,30
2099 DATA 1.3E5,CA041,9999,30,K0041,1000
2109 DATA 0.447,CA045,9E-6,30,SC045,.5
2119 DATA 47,TI044,9999,0.1,CA044,30
2129 DATA 0.907,V0049,9999,0.1,TI049,0.1
2139 DATA 4E16,V0050,9999,1000,CA040,30
2149 DATA 3.7E6,MN053,9999,0.01,CR053,0.02
2159 DATA 0.856,MN054,1E-4,0.01,CR054,0.02
2169 DATA 2.7,FE055,8E-4,0.05,MN055,0.01
2179 DATA 1E5,FE060,9999,0.05,NI060,0.05
2189 DATA 0.742,CU057,5E-4,0.05,FE057,0.05
2199 DATA 5.27,CU060,5E-5,.05,NI060,.05
2209 DATA 8E4,NI059,2E-4,.05,CU059,.05
2219 DATA 100,NI063,3E-5,.05,CU063,.2
2229 DATA 0.668,ZN065,1E-4,0.05,CU065,0.2
2239 DATA 0.786,GE068,9999,0.5,ZN068,0.05
2249 DATA 6.5E4,SE079,9999,0.01,BR079,4100
2259 DATA 2.1E5,KR081,9999,3800,BR081,4100
2269 DATA 10.73,KR085,9999,3800,BR085,5
2279 DATA 4.7E10,RR087,1E-4,5,SR087,10
2289 DATA 0.292,Y0088,9999,0.001,SR088,10
2299 DATA 29,SR090,3E-7,10,ZR090,1.
2309 DATA 9.5E5,ZR093,8E-4,1,NB093,.02
2319 DATA 2E7,NB092,9999,0.02,ZR092,1.0
2329 DATA 12,NB093M,4E-4,0.02,NB093,0.02
2339 DATA 2E4,NB094,9999,0.02,MU094,0.5
2349 DATA 3E3,MU093,8888,.02,NB093,.02
2359 DATA 2.6E6,TC097,2E-3,100,MU097,0.5
2369 DATA 1.5E6,TC098,9999,100,RU098,1.0
2379 DATA 213000,TC099,3E-4,100,RU099,1
2389 DATA 1.011,RU106,1E-5,1,PD106,.05
2399 DATA 3,RH101,9999,0.05,RU101,1.0
2409 DATA 3,RH102,9999,0.05,RU102,1.0
2419 DATA 0.567,RH102M,9999,0.05,PD102,0.05
2429 DATA 6.5E6,PD107,1E-3,.05,AG107,.001
2439 DATA 130,AG108,9999,0.001,CD108,0.05
2449 DATA 0.690,AG110M,3E-5,0.001,CD110,0.05
2459 DATA 1.241,CD109,2E-4,0.05,AG109,0.001

```


TABLE C.4 (continued) Unabridged Data File of Chemical Maximum Permissible Limits in Potable Water for Radionuclides in the Periodic Table Half-Life Greater Than One Year

2469 DATA 9E15,CD113,9999,0.01,IN113,0.02
2479 DATA 14.6,CD113M,9999,0.05,IN113,0.02
2489 DATA 5E14,IN115,9999,0.02,SN115,0.05
2499 DATA 0.315,SN113,8E-5,0.05,IN113,0.02
2509 DATA 0.671,SN119M,9999,0.05,SN119,0.05
2519 DATA 50,SN121M,9999,0.05,SB121,0.05
2529 DATA 0.353,SN123,9999,0.05,SB123,0.05
2539 DATA 1E5,SN126,4E-4,.05,TE126,.2
2549 DATA 2.73,SB125,4E-4,.05,TE125,.2
2559 DATA 0.411,TE121M,9999,0.2,SB121,0.05
2569 DATA 1.2E13,TE123,9999,0.2,SB123,0.05
2579 DATA 0.299,TE127M,5E-5,0.2,I0127,10
2589 DATA 15.9E6,I0129,6E-8,10,XE129,5900
2599 DATA 2.06,CS134,9E-6,5,BA134,.5
2609 DATA 2.3E6,CS135,1E-4,5,BA135,.5
2619 DATA 30.1,CS137,2E-5,5,BA137,.5
2629 DATA 10.4,BA133,9999,0.5,CS133,5
2639 DATA 6E4,LA137,9999,1,BA137,0.5
2649 DATA 1.05E11,LA138,9999,1,CE138,2.0
2659 DATA 0.377,CE139,9999,2,LA139,1
2669 DATA 5E16,CE142,8888,2,BA138,0.5
2679 DATA .779,CE144,1E-5,2,ND144,.2
2689 DATA 2.1E15,ND144,8888,0.2,CE140,2.0
2699 DATA 0.726,PM143,9999,1,ND143,0.2
2709 DATA 0.995,PM144,9999,1,ND144,0.2
2719 DATA 18,PM145,9999,1,ND145,0.2
2729 DATA 5.53,PM146,9999,1,ND146,0.2
2739 DATA 2.6234,PM147,2E-4,1,SM147,.2
2749 DATA 0.932,SM145,9999,0.2,ND145,0.2
2759 DATA 1E8,SM146,8888,0.2,ND142,0.2
2769 DATA 1.07E11,SM147,6E-5,0.2,ND143,0.2
2779 DATA 8E15,SM148,8888,0.2,ND144,0.2
2789 DATA 1E16,SM149,8888,0.2,ND145,0.2
2799 DATA 93,SM151,4E-4,0.2,EU151,0.2
2809 DATA 35,EU150,9999,0.2,SM150,0.2
2819 DATA 13,EU152,8E-5,.2,SM152,.2
2829 DATA 8.6,EU154,2E-5,.2,GD154,.2
2839 DATA 4.8,EU155,2E-4,.2,GD155,.2
2849 DATA 93,GD148,8888,0.2,SM144,0.2
2859 DATA 1.8E6,GD150,8888,0.2,SM146,0.2
2869 DATA 0.329,GD151,9999,0.2,EU151,0.2
2879 DATA 1.1E14,GD152,8888,0.2,SM148,0.2
2889 DATA 0.662,GD153,2E-4,0.2,EU153,0.2
2899 DATA 160,TB157,9999,0.5,GD157,0.2
2909 DATA 150,TB158,9999,0.5,DY158,1.0
2919 DATA 1E6,DY154,8888,1.0,GD150,0.2
2929 DATA 2E14,DY156,8888,1.0,GD152,0.2
2939 DATA 0.359,DY159,9999,1.0,TB159,0.5
2949 DATA 33,H0163,9999,1.0,DY163,1.0
2959 DATA 1200,H0166M,5E-2,1,ER166,.1
2969 DATA 0.353,TM170,5E-5,0.2,YB170,0.1
2979 DATA 1.92,TM171,5E-4,0.2,YB171,0.1

TABLE C.4 (continued) Unabridged Data File of Chemical Maximum
Permissible Limits in Potable Water for Radionuclides in the
Periodic Table Half-Life Greater Than One Year

2989@ATA 1.370,LUI73,9999,0.1,YR173,0.1
2999 DATA 0.427,LUI74M,9999,0.1,YR174,0.1
3009 DATA 3.561,LUI74,9999,0.1,YR174,0.1
3019 DATA 2.7E10,LUI76,9999,0.1,HF176,0.05
3029 DATA 0.441,LUI77M,1E-4,0.1,HF177,0.05
3039 DATA 1.87,HF172,9999,0.05,YR177,0.1
3049 DATA 2E15,HF174,8888,0.05,YR150,0.1
3059 DATA 30,HF178M,9999,0.05,HF178,0.05
3069 DATA 9E6,HF182,9999,0.05,W0182,100
3079 DATA 1.644,TA179,9999,1.0,HF179,0.05
3089 DATA 1.6E13,TA180,9999,1.0,W0180,100
3099 DATA 0.315,TA182,4E-5,1.0,W0182,100
3109 DATA 0.333,W0181,3E-4,100,TA181,1.0
3119 DATA 0.452,RE184M,9999,50,W0184,100
3129 DATA 5E10,RE187,2E-3,10,US187,1.0
3139 DATA 6.0,US194,9999,1.0,PT194,0.3
3149 DATA 241,IR192M,4E-5,0.8,PT192,0.3
3159 DATA 0.468,IR194M,3E-5,0.8,PT194,0.3
3169 DATA 7E11,PT190,8888,0.3,US186,1.0
3179 DATA 50,PT193,1E-3,0.3,IR193,0.8
3189 DATA 0.504,AU195,9999,0.02,PT195,0.3
#199 DATA 1.3,HG194,9999,0.005,AU194,0.02
3209 DATA 3.78,TL204,6E-5,0.005,PB204,0.01
3219 DATA 5E5,PB202,9999,0.01,HG202,0.01
3229 DATA 1.4E17,PB204,8888,0.01,HG200,0.005
3239 DATA 1.4E7,PB205,9999,0.01,TL205,0.005
3249 DATA 22.3,PB210,1E-7,0.01,PB206,0.01
3259 DATA 38,BI207,6E-5,0.1,PB207,0.01
3269 DATA 3.68E5,BI208,9999,0.1,PB208,0.01
3279 DATA 2E19,BI209,8888,0.1,TL205,0.005
3289 DATA 3.5E6,BI210,4E-5,0.1,PB206,0.01
3299 DATA 2.898,P0208,8888,.2,PB204,0.01
3309 DATA 102,P0209,8888,.2,TL205,0.005
3319 DATA 0.379,P0210,7E-7,.2,PB206,0.01
3329 DATA 1600,RA226,3.01E-8,1E-3,PB206,0.01
3339 DATA 5.75,RA228,3.01E-8,1E-3,PB208,0.01
3349 DATA 21.77,AC227,2E-6,1.0,PB207,0.01
3359 DATA 1.913,TH228,7E-6,0.05,PB208,0.01
3369 DATA 7340,TH229,8888,0.05,BI209,0.1
3379 DATA 7.7E4,TH230,2E-6,0.05,PB206,0.01
3389 DATA 1.4E10,TH232,2E-6,0.05,PB208,0.01
3399 DATA 3.25E4,PA231,9E-7,5E-3,PB207,0.01
3409 DATA 72,U0232,3E-5,0.5,PB208,0.01
3419 DATA 1.58E5,U0233,3E-5,0.5,BI209,0.1
3429 DATA 2.44E5,U0234,3E-5,0.5,BI209,0.1
3439 DATA 7.04E8,U0235,3E-5,0.5,PB207,0.01
3449 DATA 2.342E7,U0236,3E-5,0.5,TH232,0.05
3459 DATA 4.47E9,U0238,4E-5,0.5,PB206,0.01

TABLE C.4 (continued) Unabridged Data File of Chemical Maximum
Permissible Limits in Potable Water for Radionuclides in the
Periodic Table Half-Life Greater Than One Year

3469 DATA 1.084, NP235, 8888, 8E-3, PB207, 0.01
3479 DATA 1.3E6, NP236, 8888, 8E-3, PB208, 0.01
3489 DATA 2.14E6, NP237, 3.01E-6, 8E-3, BI209, 0.1
3499 DATA 2.85, PU236, 8888, 8E-4, U0236, 0.5
3509 DATA 87.8, PU238, 5E-6, 8E-4, U0234, 0.5
3519 DATA 24390, PU239, 5E-6, 8E-4, U0235, 0.5
3529 DATA 6540, PU240, 5E-6, 8E-4, U0236, 0.5
3539 DATA 15, PU241, 2E-1, 8E-4, NP237, 8E-3
3549 DATA 3.87E5, PU242, 5E-6, 8E-4, U0238, 0.5
3559 DATA 8.3E7, PU244, 4E-6, 8E-4, U0236, 0.5
3569 DATA 433, AM241, 4E-6, 4E-2, NP237, 8E-3
3579 DATA 152, AM242M, 4E-6, 4E-2, U0238, 0.5
3589 DATA 7370, AM243, 4E-6, 4E-2, U0235, 0.5
3599 DATA 0.446, CM242, 2E-5, 0.5, U0238, 0.5
3609 DATA 28, CM243, 5E-6, 0.5, U0235, 0.5
3619 DATA 17.9, CM244, 7E-6, 0.5, U236, 0.5
3629 DATA 8500, CM245, 4E-6, 0.5, NP237, 8E-3
3639 DATA 4760, CM246, 4E-6, 0.5, U0238, 0.5
3649 DATA 1.54E7, CM247, 4E-6, 0.5, U0235, 0.5
3659 DATA 3.5E5, CM248, 4E-7, 0.5, U0236, 0.5
3669 DATA 11300, CM250, 8888, 0.5, U0238, 0.5

TABLE C.5 Unabridged Data File of Solubilities of Elements
for Radionuclides in the Periodic Table with Half-Life
Greater Than One Year

DASOL3 15:40 09/09/74

2000 DATA 12.33,H0003,3E-3,300000,HE003,2
2010 DATA 1.6E6,BE010,9999,2.5E-10,B0010,1.3E+4
2020 DATA 5730,C0014,8E-4,6E-2,N0014,1E+5
2030 DATA 2.601,NA020,4E-5,1E+5,NE022,1600
2040 DATA 7.3E5,AL026,9999,4E-10,MO026,34000
2050 DATA 280,SI032,9999,56,S0032,800
2060 DATA 3.01E5,CL036,8E-5,3E+5,AR036,71
2070 DATA 269,AR039,9999,71,K0039,4E+5
2080 DATA 1.28E9,K0040,9999,4E+5,CA040,54
2090 DATA 33,AR042,9999,71,CA042,54
2100 DATA 1.3E5,CA041,9999,54,K0041,4E+5
2110 DATA 0.447,CA045,9E-6,54,SC045,3E-7
2120 DATA 47,TI044,9999,4E-17,CA044,54
2130 DATA 0.907,V0049,9999,1.5E-5,TI049,4E-17
2140 DATA 4E16,V0050,9999,1.5E-5,CA040,54
2150 DATA 3.7E6,MN053,9999,0.7,CR053,2.5E-7
2160 DATA 0.856,MN054,1E-4,0.7,CR054,2.5E-7
2170 DATA 2.7,FE055,8E-4,1.8E-9,MN055,0.7
2180 DATA 1E5,FE060,9999,1.8E-9,NI060,50
2190 DATA 0.742,C0057,5E-4,8E-3,FE057,1.8E-9
2200 DATA 5.27,C0060,5E-5,8E-3,NI060,50
2210 DATA 8E4,NI059,2E-4,50,C0059,8E-3
2220 DATA 100,NI063,3E-5,50,C0063,1.4E-2
2230 DATA 0.668,ZN065,1E-4,1,C0065,1.4E-2
2240 DATA 0.786,GE068,9999,6,ZN068,1
2250 DATA 6.5E4,SE079,9999,240,BR079,7E+5
2260 DATA 2.1E5,KR081,9999,300,BR081,7E+5
2270 DATA 10.73,KR085,9999,300,RB085,5E+5
2280 DATA 4.7E10,RB087,1E-4,5E+5,SR087,11
2290 DATA 0.292,Y0088,9999,56,SR088,11
2300 DATA 29,SR090,3E-7,11,ZR090,1E-25
2310 DATA 9.5E5,ZR093,8E-4,1E-25,NB093,8.7E-3
2320 DATA 2E7,NB092,9999,8.7E3,ZR092,1E-25
2330 DATA 12,NB093M,4E-4,8.7E-3,NB093,8.7E-3
2340 DATA 2E4,NB094,9999,8.7E-3,MU094,700
2350 DATA 3E3,MU093,9999,700,NB093,8.7E-3
2360 DATA 2.6E6,TC097,2E-3,100,MU097,700
2370 DATA 1.5E6,TC098,9999,100,RU098,8E-16
2380 DATA 213000,TC099,3E-4,100,RU099,8E-16
2390 DATA 1.011,RU106,1E-5,8E-16,PD106,4E-17
2400 DATA 3,RH101,9999,8E-10,RU101,8E-16
2410 DATA 3,RH102,9999,8E-10,RU102,8E-16
2420 DATA 0.567,RH102M,9999,8E-10,PD102,4E-17
2430 DATA 6.5E6,PD107,1E-3,4E-17,AG107,0.03
2440 DATA 130,AG108,9999,0.03,CD108,4E-4
2450 DATA 0.690,AG110M,3E-5,0.03,CD110,4E-4
2460 DATA 1.241,CD109,2E-4,4E-4,AG109,0.03
2470 DATA 9E15,CD113,9999,4E-4,IN113,5E-10

TABLE C.5 (continued) Unabridged Data File of Solubilities of
Elements for Radionuclides in the Periodic Table with Half-Life
Greater Than One Year

2480 DATA 14.6,CD113M,9999,4E-4,IN113,5E-10
2490 DATA 5E14,IN115,9999,5E-10,SN115,2E-26
2500 DATA 0.315,SN113,8E-5,2E-26,IN113,2E-10
2510 DATA 0.671,SN119M,9999,2E-26,SN119,2E-26
2520 DATA 50,SN121M,9999,2E-26,SB121,2.5E-6
2530 DATA 0.353,SN123,9999,2E-26,SB123,2.5E-6
2540 DATA 1E5,SN126,4E-4,2E-26,TE126,5
2550 DATA 2.73,SB125,4E-4,2.5E-6,TE125,5
2560 DATA 0.411,TE121M,9999,5,SB121,2.5E-6
2570 DATA 1.2E13,TE123,9999,5,SB123,2.5E-6
2580 DATA 0.299,TE127M,5E-5,5,I0127,6E+5
2590 DATA 15.9E6,I0129,6E-8,6E5,XE129,1000
2600 DATA 2.06,CS134,9E-6,6E5,BA134,0.04
2610 DATA 2.3E6,CS135,1E-4,6E5,BA135,0.04
2620 DATA 30.1,CS137,2E-5,6E5,BA137,0.04
2630 DATA 10.4,BA133,9999,0.04,CS133,6E+5
2640 DATA 6E4,LA137,9999,1E+4,BA137,0.04
2650 DATA 1.05E11,LA138,9999,1E+4,CE138,1.3E+4
2660 DATA 0.377,CE139,9999,1.3E+4,LA139,1E+4
2670 DATA 5E16,CE142,8888,1.3E+4,BA138,0.04
2680 DATA .779,CE144,1E-5,1.3E4,ND144,2200
2690 DATA 2.1E15,ND144,8888,2200,CE140,1.3E+4
2700 DATA 0.726,PM143,9999,1200,ND143,2200
2710 DATA 0.995,PM144,9999,1200,ND144,2200
2720 DATA 18,PM145,9999,1200,ND145,2200
2730 DATA 5.53,PM146,9999,1200,ND146,2200
2740 DATA 2.6234,PM147,2E-4,1200,SM147,810
2750 DATA 0.932,SM145,9999,810,ND145,2200
2760 DATA 1E8,SM146,8888,810,ND142,2200
2770 DATA 1.07E11,SM147,6E-5,810,ND143,2200
2780 DATA 8E15,SM148,8888,810,ND144,2200
2790 DATA 1E16,SM149,8888,810,ND145,2200
2800 DATA 93,SM151,4E-4,810,EUI51,410
2810 DATA 35,EUI50,9999,410,SM150,810
2820 DATA 13,EUI52,8E-5,410,SM152,810
2830 DATA 8.6,EUI54,2E-5,410,GDI54,260
2840 DATA 4.8,EUI55,2E-4,410,GDI55,260.
2850 DATA 93,GDI48,8888,260,SM144,810
2860 DATA 1.8E6,GDI50,8888,260,SM146,810
2870 DATA 0.329,GDI51,9999,260,EUI51,410
2880 DATA 1.1E14,GDI52,8888,260,SM148,810
2890 DATA 0.662,GDI53,2E-4,260,EUI53,410
2900 DATA 160,TB157,9999,160,GDI57,260
2910 DATA 150,TB158,9999,160,DY158,100
2920 DATA 1E6,DY154,8888,100,GDI50,260
2930 DATA 2E14,DY156,8888,100,GDI52,260
2940 DATA 0.359,DY159,9999,100,TB159,160
2950 DATA 33,H0163,9999,50,DY163,100
2960 DATA 1200,H0166M,5E-2,50,ER166,20
2970 DATA 0.353,TM170,5E-5,5,YB170,4

TABLE C.5 (continued) Unabridged Data File of Solubilities
of Elements for Radionuclides in the Periodic Table with
Half-Life Greater than One Year

2980 DATA 1.92, TM171, 5E-4, 5, YB171, 4
2990 DATA 1.370, LU173, 9999, 0.15, YB173, 4
3000 DATA 0.427, LU174M, 9999, 0.15, YB174, 4
3010 DATA 3.561, LU174, 9999, 0.15, YB174, 4
3020 DATA 2.7E10, LU176, 9999, 0.15, HF176, 1E+5
3030 DATA 0.441, LU177M, 1E-4, 0.15, HF177, 1E+5
3040 DATA 1.87, HF172, 9999, 1E+5, YB177, 4
3050 DATA 2E15, HF174, 8888, 1E+5, YB150, 4
3060 DATA 30, HF178M, 9999, 1E+5, HF178, 1E+5
3070 DATA 9E6, HF182, 9999, 1E+5, W0182, 2
3080 DATA 1.644, TA179, 9999, 100, HF179, 1E+5
3090 DATA 1.6E13, TA180, 9999, 100, W0180, 2
3100 DATA 0.315, TA182, 4E-5, 100, W0182, 2
3110 DATA 0.333, W0181, 3E-4, 2, TA181, 100
3120 DATA 0.452, RE184M, 9999, 100, W0184, 2
3130 DATA 5E10, RE187, 2E-3, 100, OS187, 4.5E+4
3140 DATA 6.0, OS194, 9999, 4.5E+4, PT194, 8E-18
3150 DATA 241, IR192M, 4E-5, 2, PT192, 8E-18
3160 DATA 0.468, IR194M, 3E-5, 2, PT194, 8E-18
3170 DATA 7E11, PT190, 8888, 8E-18, OS186, 4.5E+4
3180 DATA 50, PT193, 1E-3, 8E-18, IR193, 2
3190 DATA 0.504, AU195, 9999, 9E-22, PT195, 8E-18
3200 DATA 1.3, HG194, 9999, 1.4E-8, AU194, 9E-22
3210 DATA 3.78, TL204, 6E-5, 4E+4, PB204, 9.5E-4
3220 DATA 5E5, PB202, 9999, 9.5E-4, HG202, 1.4E-8
3230 DATA 1.4E17, PB204, 8888, 9.5E-4, HG200, 1.4E-8
3240 DATA 1.4E7, PB205, 9999, 9.5E-4, TL205, 4E+4
3250 DATA 22.3, PB210, 1E-7, 9.5E-4, PB206, 9.5E-4
3260 DATA 38, BI207, 6E-5, 1, PB207, 9.5E-4
3270 DATA 3.68E5, BI208, 9999, 1, PB208, 9.5E-4
3280 DATA 2E19, BI209, 8888, 1, TL205, 4E+4
3290 DATA 3.5E6, BI210, 4E-5, 1, PB206, 9.5E-4
3300 DATA 2.898, PO208, 8888, 100, PB204, 9.5E-4
3310 DATA 102, PO209, 8888, 100, TL205, 4E+4
3320 DATA 0.379, PO210, 7E-7, 100, PB206, 9.5E-4
3330 DATA 1600, RA226, 3.01E-8, 0.025, PB206, 9.5E-4
3340 DATA 5.75, RA228, 3.01E-8, 0.025, PB208, 9.5E-4
3350 DATA 21.77, AC227, 2E-6, 2E+5, PB207, 9.5E-4
3360 DATA 1.913, TH228, 7E-6, 1.5E-14, PB208, 9.5E-4
3370 DATA 7340, TH229, 8888, 1.5E-14, BI209, 1
3380 DATA 7.7E4, TH230, 2E-6, 1.5E-14, PB206, 9.5E-4
3390 DATA 1.4E10, TH232, 2E-6, 1.5E-14, PB208, 9.5E-4
3400 DATA 3.25E4, PA231, 9E-7, 10, PB207, 9.5E-4
3410 DATA 72, UO232, 3E-5, 9.5E-5, PB208, 9.5E-4
3420 DATA 1.58E5, UO233, 3E-5, 9.5E-5, BI209, 1
3430 DATA 2.44E5, UO234, 3E-5, 9.5E-5, BI209, 1
3440 DATA 7.04E8, UO235, 3E-5, 9.5E-5, PB207, 9.5E-4
3450 DATA 2.342E7, UO236, 3E-5, 9.5E-5, TH232, 1.5E-14
3460 DATA 4.47E9, UO238, 4E-5, 9.5E-5, PB206, 9.5E-4

TABLE C.5 (continued) Unabridged Data File of Solubilities
of Elements for Radionuclides in the Periodic Table with
Half-Life Greater Than One Year

3470 DATA 1.084, NP235, 8888, 500, PB207, 9.5E-4
3480 DATA 1.3E6, NP236, 8888, 500, PB208, 9.5E-4
3490 DATA 2.14E6, NP237, 3.01E-6, 500, BI209, 1
3500 DATA 2.85, PU236, 8888, 3E-05, UO236, 9.5E-5
3510 DATA 87.8, PU238, 5E-6, 3E-05, UO234, 9.5E-5
3520 DATA 24390, PU239, 5E-6, 3E-05, UO235, 9.5E-5
3530 DATA 6540, PU240, 5E-6, 3E-05, UO236, 9.5E-5
3540 DATA 15, PU241, 2E-4, 3E-05, NP237, 500.
3550 DATA 3.87E5, PU242, 5E-6, 3E-05, UO238, 9.5E-5
3560 DATA 8.3E7, PU244, 4E-6, 3E-05, UO236, 9.5E-5
3570 DATA 433, AM241, 4E-6, 4000, NP237, 500
3580 DATA 152, AM242M, 4E-6, 4000, UO238, 9.5E-5
3590 DATA 7370, AM243, 4E-6, 4000, UO235, 9.5E-5
3600 DATA 0.446, CM242, 2E-5, 40000, UO238, 9.5E-5
3610 DATA 28, CM243, 5E-6, 40000, UO235, 9.5E-5
3620 DATA 17.9, CM244, 7E-6, 40000, UO236, 9.5E-5
3630 DATA 8500, CM245, 4E-6, 40000, NP237, 500
3640 DATA 4760, CM246, 4E-6, 40000, UO238, 9.5E-5
3650 DATA 1.54E7, CM247, 4E-6, 40000, UO235, 9.5E-5
3660 DATA 3.5E5, CM248, 4E-7, 40000, UO236, 9.5E-5
3670 DATA 11300, CM250, 8888, 40000, UO238, 9.5E-5

REFERENCES

1. Code of Federal Regulations, 10CFR20, "Standards for Protection Against Radiation," GPO, Washington, D.C., 1971.
2. G. W. Dawson, The Chemical Toxicity of Radionuclides, BNWL-1815, Battelle Pacific Northwest Laboratories, Richland, WA, June 1974.
3. D. H. Denham, D. A. Baker, J. K. Soldat and J. P. Corley, Radiological Evaluations for Advanced Waste Management Studies, p. 29, BNWL-1764, Battelle Pacific Northwest Laboratories, Richland, WA, September 1973.
4. G. K. Schweitzer and M. Jackson, "Radiocolloids," J. Chem. Educ., Vol. 29, pp. 513-522, 1952.
5. Periodic Table of the Elements, Sargent-Welch Scientific Company, 1972.
6. J. H. Perry, Chemical Engineers' Handbook, 4th Ed., McGraw-Hill, 1963.
7. A. Seidell, Solubilities of Inorganic Compounds, Van Nostrand, 1956.
8. L. Meites, Handbook of Analytical Chemical Chemistry, 1st Ed., McGraw-Hill, 1963.
9. W. M. Latimer, Reference Book of Inorganic Chemistry, Macmillan, 1951.
10. N. A. Lange, Handbook of Chemistry, 10th Ed., McGraw-Hill, 1956.
11. C. H. Sorum, Introduction to Semimicro Qualitative Analysis, Prentice-Hall, 1967.
12. A. R. Middleton and J. W. Willard, Semimicro Qualitative Analysis, Prentice-Hall, 1947.
13. M. Pourbaix, Atlas of Electrochemical Equilibria in Aqueous Solutions, Pergamon Press, 1966.
14. I. M. Korenman, "The Solubility Products of Hydroxides of Some Rare Elements," J. of Gen. Chem., 1955.
15. T. Moeller, and H. E. Kremers, "Basicity of Scandium, Yttrium, and Lanthanide Rare Earths," Chemical Reviews, 1945.
16. V. A. Mikhailov, Analytical Chemistry of Neptunium, Halstead, 1973.
17. W. L. Polzer, "Solubility of Plutonium in Soil-Water Environments - A Theoretical Study," Proceedings of the Rocky Flats Symposium on Safety in Plutonium Handling Facilities, April 16, 1971.

18. H. C. Hodge, J. C. Stannard, J. B. Hursh, Uranium, Plutonium Transplutonic Elements, Springer-Verlag, 1973.
19. K. J. Schneider, Editor, Advanced Waste Management Studies Progress Report, January-February-March 1974, pp. 25-30, BNWL-B-223-10, Battelle Pacific Northwest Laboratories, Richland, WA, May 1974.
20. F. C. Loughnan, Chemical Weathering of the Silicate Minerals, Elsevier, 1969.
21. G. B. Heisig, The Theory and Practice of Semimicro Qualitative Analysis, Saunders, 1943.

DISTRIBUTION

No. of
Copies

OFFSITE

- 2 ERDA Division of Waste Management
and Transportation
Washington, DC 20545

F. K. Pittman
R. W. Ramsey

- 1 ERDA Holifield National Laboratory
P.O. Box X
Oak Ridge, TN 37830

W. C. McLain

- 27 ERDA Technical Information Center

ONSITE

- 3 ERDA Richland Operations Office
Production and Waste Management
Programs Division

R. B. Goranson
N. T. Karagianes
F. R. Standerfer

- 1 Atlantic Richfield Hanford Company

A. E. Smith

- 26 Battelle-Northwest

D. A. Baker
J. W. Bartlett
H. C. Burkholder (5)
T. R. Card (3)
J. P. Corley
G. W. Dawson
J. R. Eliason
G. Jansen (5)
A. M. Platt
R. C. Routson
J. K. Soldat
W. K. Winegardner
Technical Information Files (3)
Technical Publications