8. REGULATIONS AND ADVISORIES

The international, national, and state regulations and guidelines regarding stable strontium in air, water, and other media are summarized in Table 8-1. The regulations and guidelines regarding radioactive strontium are summarized in Tables 8-2 and 8-3.

Stable Strontium. An MRL of 2.0 mg strontium/kg/day for intermediate-duration oral exposure to strontium was calculated by dividing a NOAEL of 140 mg strontium/kg/day for skeletal toxicity in young rats (Storey 1961) by an uncertainty factor of 30 and a modifying factor of 3 (see Appendix A).

The EPA derived a chronic reference dose (RfD) of 0.6 mg/kg/day for strontium (IRIS 2002). The RfD is based on a NOAEL of 190 mg strontium/kg/day for skeletal toxicity in young rats (Storey 1961).

The EPA has not classified stable strontium for human carcinogenicity (IRIS 2002). A number of agencies have classified strontium chromate as a human carcinogen by the inhalation route, on the basis of occupational and animal studies. The carcinogenicity of strontium chromate is attributed to the hexavalent chromium ion and not to strontium. The American Conference of Governmental Industrial Hygienists (ACGIH) has given strontium chromate the classification A2, suspected human carcinogen, and has established an 8-hour time-weighted-average (TWA) of 0.0005 mg/m^3 for occupational exposure (ACGIH 2002). The International Agency for Research on Cancer (IARC) has assigned strontium chromate, along with other chromates, to Group 1, as a human carcinogen (IARC 1990, 2002a). No other stable strontium compound is listed by IARC.

Radioactive Strontium. No MRLs were derived for inhalation or oral exposures to radioactive strontium. The EPA has not derived reference concentrations (RfCs) or RfDs for radioactive strontium (IRIS 2002), nor does the Integrated Risk Information System (IRIS) database provide cancer assessments for radioisotopes of strontium. This function is the responsibility of the EPA Office of Radiation and Indoor Air (ORIA). All radionuclides, including radioisotopes of strontium, are classified as known human (Group A) carcinogens. This classification is based on results of epidemiological studies of Japanese atomic bomb survivors, underground uranium miners, radium dial painters, and patients subjected to a variety of radiation treatments, as well as results of laboratory animal research and mammalian tissue culture studies. ORIA has published cancer slope factors (mortality and morbidity cancer risk estimates) for all known radionuclides, by various exposure routes (inhalation, drinking water ingestion, food ingestion, soil ingestion, immersion in a cloud, and external exposure from contaminated soil) for five age

Table 8-1. Regulations and Guidelines Applicable to Stable Strontium

Agency	Description	Information	Reference
INTERNATIONAL			
Guidelines:			
IARC	Carcinogenicity classification		IARC 1990, 2001a
	Strontium chromate	Group 1[a]	
NATIONAL			
Regulations and Guidelines:			
a. Air			
ACGIH	TLV (8-hour TWA)		ACGIH 2002
	Strontium chromate	$10x5^{-4}$ mg/m^3	
EPA	HAP		HSDB 2001
	Strontium chromate		
NIOSH	REL	No data	
OSHA	PEL	No data	
b. Water			
EPA	Drinking water guideline	4 mg/L	HSDB 2001
	Health Advisories		EPA 2000d
	10-kg child		
	1 Day	25 mg/L	
	10 Day	25 mg/L	
	Lifetime	4 mg/L	
	DWEL	20 mg/L	
USNRC	Maximum ambient environmental level in potable water	10 mg/L	HSDB 2001
c. Food		No data	
d. Other			
ACGIH	Carcinogenicity classification		ACGIH 2002
	Strontium chromate	A2[b]	
EPA	Carcinogenicity classification	Group D[c]	EPA 2000d
	RfD	$6x10^{-1}$ mg/kg/day	IRIS 2001
	Reportable quantity		EPA 2001a
	Strontium chromate	1,000 pounds	40CFR302.4
	Toxic pollutants and hazardous substances required to be identified		EPA 2001b 40CFR122, Appendix D
STATE			
a. Air		No data	
b. Water			
Florida	Drinking water guideline	4.2 mg/L	HSDB 2001
Maine	Drinking water guideline	2.4 mg/L	HSDB 2001
c. Food		No data	
d. Other			
Arizona	Soil remediation levels		BNA 2001
	Residential	$4.6x10^4$ mg/kg	
	Non residential	$1x10^6$ mg/kg	

Table 8-1. Regulations and Guidelines Applicable to Stable Strontium

Agency	Description	Information	Reference
STATE (*cont.*)			
Florida	Toxic substances in the workplace; Florida substance list	Strontium chromate	BNA 2001

[a]Group 1: carcinogenic to humans (refers to hexavalent chromium)
[b]A2: suspected human carcinogen (refers to hexavalent chromium)
[c]Group D: not classifiable as to human carcinogenicity

ACGIH = American Conference of Governmental Industrial Hygienists; BNA = Bureau of National Affairs; CFR = Code of Federal Regulations; DWEL = drinking water equivalent level; EPA = Environmental Protection Agency; HAP = hazardous air pollutant; HSDB = Hazardous Substances Data Bank; IARC = International Agency for Research on Cancer; IRIS = Integrated Risk Information System; NIOSH = National Institute for Occupational Safety and Health; OSHA = Occupational Safety and Health Administration; PEL = permissible exposure limit; REL = recommended exposure limit; RfD = reference dose; TLV = threshold limit values; TWA = time-weighted averages; USNRC = National Research Council

Table 8-2. Regulations and Guidelines Applicable to Radioactive Strontium

Agency	Description	Information	Reference
INTERNATIONAL			
Guidelines:			
a. Occupational			
ICRP	Recommended dose limits[a]; effective dose	20 mSv per year, averaged over defined period of 5 years[b]	ICRP 1994b
	Annual equivalent dose		
	Lens of the eye	150 mSv	
	Skin[c]	500 mSv	
	Hands and feet	500 mSv	
b. General Population			
IARC	Carcinogenicity classification	Group 1[d]	IARC 2001b, 2001c
ICRP	Recommended dose limits[a]		ICRP 1994b
	Effective dose	1 mSv per year[e]	
	Annual equivalent dose in		
	Lens of the eye	15 mSv	
	Skin[c]	50 mSv	
	Hands and feet	No data	
NATIONAL			
Regulations:			
a. Air			
EPA	Concentration levels for environmental compliance for ^{90}Sr	1.9×10^{-14} Ci/m^3	EPA 2001d 40CFR61, Appendix E
	Methods for estimating radionuclide emissions		EPA 2001m 40CFR61, Appendix D
	Test method for measuring radionuclide emissions from stationary sources	Method 114	EPA 2001e 40CFR61, Appendix B
OSHA	Safety and health regulations for construction for ionizing radiation	10CFR20 regulations apply	OSHA 2001 29CFR1926.53
	Toxic and hazardous substances for ionizing radiation		OSHA 2000 29CFR1910.1096
USNRC	Effluent concentrations in air		USNRC 2001g 10CFR20, Appendix B
	^{90}Sr		
	Class D[f]	3×10^{-11} µCi/mL	
	Class Y[g]	6×10^{-12} µCi/mL	
	Occupational values via inhalation	ALI (µCi) / DAC(µCi/mL)	USNRC 2001g 10CFR20, Appendix B
	^{90}Sr		
	Class D[f]	2×10^{1} / 8×10^{-9}	
	Class Y[g]	4×10^{0} / 2×10^{-9}	

Table 8-2. Regulations and Guidelines Applicable to Radioactive Strontium

Agency	Description	Information	Reference
NATIONAL *(cont.)*			
b. Water			
EPA	Analytical methods for radioactivity of ^{90}Sr	Radio chemical	EPA 2001g 40CFR141.25 (a)
	Detection limits for man-made beta particle and photon emitters for ^{90}Sr	2 pCi/L	EPA 2001g 40CFR141.25 (c)(2), Table B
	Maximum contaminant levels in community water systems; average annual concentrations assumed to produce a total body or organ dose of 4 millirem/year		EPA 2001f 40CFR141.16
	^{90}Sr	8 pCi/L	
	Critical organ	Bone marrow	
	Monitoring frequency for radioactivity in community water systems; annual monitoring	Analysis of four quarterly samples	EPA 2001h 40CFR141.26 (b)(4)
USNRC	Effluent concentrations in water		USNRC 2001g 10CFR20, Appendix B
	^{90}Sr		
	Class D[f]	$5x10^{-7}$ µCi/mL	
	Releases to sewers; monthly average concentration		USNRC 2001g 10CFR20, Appendix B
	^{90}Sr		
	Class D[f]	$5x10^{-6}$ µCi/mL	
c. Food			
FDA	Sources of radiation used for inspection of food; sealed units producing radiation	≤2.2 million electron volts	FDA 2000 21CFR179.21
d. Other: Occupational			
DOE	Individual monitoring		DOE 2001a 10CFR835.402
	Limits for members of the public entering a controlled area (total effective dose equivalent in a year)	0.01 rem (0.001 Sv)	DOE 2001b 10CFR835.208
	Limits for the embryo/fetus from conception to birth	0.5 rem (0.005 Sv)	DOE 2001c 10CFR835.206
	Occupational dose limits for general employees; total effective dose equivalent	5 rems (0.05 Sv)	DOE 2001d 10CFR835.202

Table 8-2. Regulations and Guidelines Applicable to Radioactive Strontium

Agency	Description	Information	Reference
NATIONAL *(cont.)*			
DOE	Occupational dose limits for general employees; sum of the deep dose equivalent for external exposures and the committed dose equivalent to any organ or tissue other than the lens of the eye	50 rems (0.5 Sv)	DOE 2001d 10CFR835.202
	Occupational dose limits for general employees		DOE 2001d 10CFR835.202
	Lens of the eye dose equivalent	15 rems (0.15 Sv)	
	Shallow dose equivalent to the skin or to any extremity	50 rems (0.5 Sv)	
	Planned special exposures		
	Occupational dose limits for minors (total effective dose equivalent in a year)	0.1 rem (0.001 Sv)	DOE 2001e 10CFR835.207
	Radiation standards; inhaled air DAC for lung retention		DOE 2000b 10CFR835, Appendix A
	^{90}Sr		
	Class D[h]	8×10^{-9} µCi/mL	
	Class W[i]	No data	
	Class Y[j]	2×10^{-9} µCi/mL	
DOT	Activity values for radio-nuclides		DOT 2001b 49CFR173.435
	^{90}Sr		
	A_1	5.41 Ci	
	A_2	2.70 Ci	
	Carriage by public highway; requirements for Class 7 (radioactive material); total transport index number	50	DOT 2001c 49CFR177.842
	General requirements for shipments and packages; Class 7 (radioactive) materials		DOT 2001d 49CFR173 Subpart I
	Scope and definitions		49CFR173.401 thru 403
	General design requirements		49CFR173.410
	Table of activity limits-excepted quantities and articles		49CFR173.425
	General requirements for shipments and packages; Class 7 (radioactive) materials		DOT 2001d 49CFR173 Subpart I

Table 8-2. Regulations and Guidelines Applicable to Radioactive Strontium

Agency	Description	Information	Reference
NATIONAL *(cont.)*			
DOT	Requirements for determining A1 and A2 values for radionuclides and for the listing of radionuclides on shipping papers and labels		DOT 2001d 49CFR173.433
	Radiation level limitations; any normally occupied space except carriers operating under the provisions of a state or federally regulated radiation protection program and wearing radiation dosimetry devices	0.02 mSv/hour (2 mrem/hour)	DOT 2001e 49CFR173.441
	Radiation level limitations; any point 2 meters (6.6 feet) from the outer lateral surfaces, excluding top and underside	0.1 mSv/hour (10 mrem/hour)	DOT 2001e 49CFR173.441
	Radiation level limitations; external surface radiation level not to be exceeded under conditions normally incident to transportation packages exceeding the radiation limit	2 mSv/hour (200 mrem/hour) and the transport index (TI) is less than 10	DOT 2001e 49CFR173.441
	Transport by exclusive use shipment		
	Conditional maximum radiation level	10 mSv/hour (1,000 mrem/hour)	
	Outer surface of vehicles including top and underside	2 mSv/hour (200 mrem/hour)	
	Superfund; reportable quantity for ^{90}Sr	0.1 pounds	DOT 2001a 49CFR172.101, Appendix A, Table 2
e. Other: General Population			
EPA	Annual possession quantities for environmental compliance of ^{90}Sr		EPA 2001d 40CFR61, Appendix E
	Gaseous form	5.2×10^{-4} Ci/year	
	Liquid/powder forms	5.2×10^{-1} Ci/year	
	Solid form	5.2×10^{2} Ci/year	

Table 8-2. Regulations and Guidelines Applicable to Radioactive Strontium

Agency	Description	Information	Reference
NATIONAL *(cont.)*			
EPA	Environmental standards for management and storage of spent nuclear fuel, high-level and transuranic radioactive wastes; applicability and definitions		EPA 2001i 40CFR191, Subpart A
	Whole body	25 mrem	
	Thyroid	75 mrem	
	Other critical organs	25 mrem	
	Environmental standards for disposal of spent nuclear fuel, high-level and transuranic radioactive wastes; applicability, definitions, containment and individual protection requirements		EPA 2001i 40CFR191, Subpart B
	Environmental standards for groundwater protection of spent nuclear fuel, high-level and transuranic radioactive wastes; applicability and definitions; release limits for containment requirements of ^{90}Sr	1,000/1,000 MTHM	EPA 2001i 40CFR191, Subpart C
	Hazardous waste injection restrictions; waste specific prohibitions; newly listed and identified wastes	D004–D011 wastes	EPA 2001j 40CFR148.18
	Land disposal restrictions; effective dates of injected prohibited hazardous wastes		EPA 2001l 40CFR268, Appendix VIII
	Radioactive waste; release limits for containment requirements[k] for ^{90}Sr	1,000 Ci	EPA 2001c 40CFR191, Appendix A
	Reportable quantity of ^{90}Sr	$1x10^{-1}$ Ci	EPA 2001e 40CFR302.4, Appendix B
	Standards for the control of residual radioactive materials from inactive uranium processing sites; definitions; control of residual radioactive materials and their listed constituents		EPA 2001k 40CFR192, Subpart A

Table 8-2. Regulations and Guidelines Applicable to Radioactive Strontium

Agency	Description	Information	Reference
NATIONAL *(cont.)*			
EPA	Standards for cleanup of land and buildings contaminated with residual radioactive materials from inactive uranium processing sites		EPA 2001k 40CFR192, Subpart B
	Guidance for implementation		EPA 2001k 40CFR192, Subpart C
	Standards for management of uranium byproduct materials pursuant to Section 84 of the Atomic Energy Act of 1954, as amended		EPA 2001k 40CFR192, Subpart D
	Standards for management of thorium byproduct materials pursuant to Section 84 of the Atomic Energy Act of 1954, as amended		EPA 2001k 40CFR192, Subpart E
	Underground injection control regulations for Class V injection wells		EPA 2001n 63FR40586
USNRC	Activity values for radionuclides (^{90}Sr) A_1 A_2 Specific gravity	 5.41 Ci 2.70 Ci 1.4×10^{2} Ci	USNRC 2001i 10CFR71, Table A-1
	Byproduct material listing (^{90}Sr) Column 1 Column 2	 1×10^{-2} Ci 1×19^{-4} Ci	USNRC 2001b 10CFR33.100, Schedule A
	Byproduct material listing	0.1 µCi	USNRC 2001a 10CFR30.71, Schedule B
	Dose to an embryo/fetus (dose equivalent during the entire pregnancy)	0.5 rem (5 mSv)	USNRC 2001m 10CFR20.1208
	Licensing ice detection devices (^{90}Sr)	≤50 µCi	USNRC 2001c 10CFR31.10
	Occupational dose limits for adults (total effective dose equivalent) in a year	5 rems (0.05 Sv)	USNRC 2001n 10CFR20.1201
	Sum of the deep-dose equivalent and the committed dose equivalent to any individual organ or tissue other than the lens of the eye	50 rems (0.5 Sv)	USNRC 2001n 10CFR20.1201

Table 8-2. Regulations and Guidelines Applicable to Radioactive Strontium

Agency	Description	Information	Reference
NATIONAL *(cont.)*			
USNRC	Annual limits to the lens of the eye, to the skin, and to the extremities		USNRC 2001n 10CFR20.1201
	Lens dose equivalent	15 rems (0.15 Sv)	
	Shallow-dose equivalent to the skin or to any extremity	50 rems (0.50 Sv)	
	Occupational dose limits for minors	10% of the annual dose limits specified for adult workers in 10 CFR 20.1201	USNRC 2001o 10CFR20.1207
	Occupational values for oral ingestion (ALI) of ^{90}Sr		USNRC 2001g 10CFR20, Appendix B
	Class D[f]	$3x10^{1}$ µCi (bone surf) $4x10^{1}$	
	Medical use—^{90}Sr as a use of unsealed byproduct material for uptake, dilution, and excretion studies		USNRC 2001k 10CFR35.100
	Medical use—^{90}Sr as a sealed source in an applicator for treatment of superficial eye conditions		USNRC 2001j 10CFR35.4000
	Physical protection for spent nuclear fuel and high-level radioactive waste		USNRC 2001p 63FR26955
	Radioactive waste; classification of ^{90}Sr		USNRC 2001l 10CFR61.55
	Column 1[l]	0.04 Ci/m^3	
	Column 2	150 Ci/m^3	
	Column 3	7,000 Ci/m^3	
	Standards for protection against radiation—dose limits for individual members of the public; total effective dose equivalent to individual	0.1 rem/year	USNRC 2001q 10CFR20.1301
	Standards for protection against radiation; dose limits for individual members of the public; dose from external source	0.002 rem/hour	USNRC 2001q 10CFR20.1301
	Quality assurance—^{90}Sr		USNRC 2001h 10CFR32.62
	Quantity of licensed material requiring labeling containing ^{90}Sr	$1.2x10^{-1}$ µCi	USNRC 2001d 10CFR30, Appendix B

Table 8-2. Regulations and Guidelines Applicable to Radioactive Strontium

Agency	Description	Information	Reference
NATIONAL *(cont.)*			
USNRC	Quantity of radioactive material requiring need for an emergency plan for responding to a release (^{90}Sr)		USNRC 2001f 10CFR30.72, Schedule C
	Release fraction	0.01%	
	Quantity	90 Ci	
	Standards for protection against radiation; quantity of licensed material requiring labeling (^{90}Sr)	$1x10^{-1}$ µCi	USNRC 2001e 10CFR20, Appendix C
NATIONAL Guidelines:			
a. Air			
ACGIH	TLV-TWA (^{90}Sr)	Rdiation exposures must be kept as low as reasonable achievable	ACGIH 2002
	Effective dose		ACGIH 2002
	Any single year	50 mSv	
	Averaged over 5 years	20 mSv	
	Annual equivalent dose to		ACGIH 2002
	Lens of the eye	150 mSv	
	Skin	500 mSv	
	Hands and feet	500 mSv	
	Embryo-fetus exposures once the pregnancy is known		ACGIH 2002
	Monthly equivalent dose	0.5 mSv	
	Dose to the surface of women's abdomen (lower trunk)	2 mSv for the remainder of the pregnancy	
	Intake of radionuclide	1/20 ALI	
NIOSH	REL (TWA)	No data	
b. Water			
EPA	MCLG for beta particles	No final MCLG, but zero proposed in 1991	EPA 2000d
	MCL for beta particles	4 mrem	EPA 2000d
	Health advisory for beta particle activity in drinking water	4 mrem/year at 10^{-4} cancer risk	EPA 2000d
	Cancer group	Group A[m]	EPA 2000d
c. Food			
FDA	Derived intervention level[n] (DIL; Bq/kg food) for in accidentally-contaminated human food		FDA 1998
	^{89}Sr	400[o]	
	^{90}Sr	160[p]	

Table 8-2. Regulations and Guidelines Applicable to Radioactive Strontium

Agency	Description	Information	Reference
NATIONAL *(cont.)*			
d. Other			
EPA	Effective dose equivalent		EPA 1987
	Adult	5 rem/year	Federal Register
	Lens of the eye	15 rem/year	Part II
	All other organs	50 rem/year	
	Juvenile workers (<18 years old)	0.5 rem/year	
	Pregnant workers	0.5 rem/gestation period	
	Carcinogenicity slope factors[q] Ingestion—lifetime excess total cancer risk/pCi		EPA 2002
	Water		
	^{82}Sr	3.13×10^{-11}	
	^{85}Sr	2.26×10^{-12}	
	^{85m}Sr	1.67×10^{-14}	
	^{89}Sr	1.28×10^{-11}	
	^{90}Sr	5.59×10^{-11}	
	$^{90+disentegration}Sr$	7.40×10^{-11}	
	^{91}Sr	3.22×10^{-12}	
	^{92}Sr	2.25×10^{-12}	
	Carcinogenicity slope factors[q] Ingestion—lifetime excess total cancer risk/pCi		EPA 2002
	Food		
	^{82}Sr	4.48×10^{-11}	
	^{85}Sr	3.11×10^{-12}	
	^{85m}Sr	2.31×10^{-14}	
	^{89}Sr	1.84×10^{-11}	
	^{90}Sr	6.88×10^{-11}	
	$^{90+disentegration}Sr$	9.53×10^{-11}	
	^{91}Sr	4.66×10^{-12}	
	^{92}Sr	3.26×10^{-12}	
	Carcinogenicity slope factors[q] Ingestion—lifetime excess total cancer risk/pCi		EPA 2002
	Soil		
	^{82}Sr	8.47×10^{-11}	
	^{85}Sr	5.03×10^{-12}	
	^{85m}Sr	3.74×10^{-14}	
	^{89}Sr	3.47×10^{-11}	
	^{90}Sr	9.18×10^{-11}	
	$^{90+disentegration}Sr$	1.44×10^{-10}	
	^{91}Sr	8.81×10^{-12}	
	^{92}Sr	6.18×10^{-12}	

Table 8-2. Regulations and Guidelines Applicable to Radioactive Strontium

Agency	Description	Information	Reference
NATIONAL *(cont.)*			
EPA	Carcinogenicity slope factors[r] Inhalation—lifetime excess total cancer risk/pCi		EPA 2002
	^{82}Sr	3.69×10^{-11}	
	^{85}Sr	2.56×10^{-12}	
	^{85m}Sr	8.32×10^{-15}	
	^{89}Sr	2.34×10^{-11}	
	^{90}Sr	1.05×10^{-10}	
	$^{90+disentegration}Sr$	1.13×10^{-10}	
	^{91}Sr	1.70×10^{-12}	
	^{92}Sr	1.03×10^{-12}	
	Carcinogenicity slope factors[s] External exposure—risk/year per pCi/g in soil		EPA 2002
	^{82}Sr	5.00×10^{-11}	
	^{85}Sr	2.20×10^{-6}	
	^{85m}Sr	8.21×10^{-7}	
	^{89}Sr	7.19×10^{-9}	
	^{90}Sr	4.82×10^{-10}	
	$^{90+disentegration}Sr$	1.96×10^{-8}	
	^{91}Sr	3.30×10^{-6}	
	^{92}Sr	6.69×10^{-6}	
NCRP	Occupational exposures[t] Effective dose limits		NCRP 1993
	Annual	50 mSv	
	Cumulative	10 mSv x age	
	Occupational exposures[t] Equivalent dose annual limits for tissues and organs		NCRP 1993
	Lens of eye	150 mSv	
	Skin, hands, and feet	500 mSv	
	Public exposures (annual) Effective dose limit, continuous or frequent exposure[s]	1 mSv	NCRP 1993
	Public exposures (annual) Effective dose limit, infrequent exposure[t]	5 mSv	NCRP 1993
	Public exposures (annual) Equivalent dose limits for tissues and organs[t]		NCRP 1993
	Lens of eye	15 mSv	
	Skin, hands, and feet	50 mSv	

Table 8-2. Regulations and Guidelines Applicable to Radioactive Strontium

Agency	Description	Information	Reference
STATE			
a. Air			
Arkansas	Concentrations in air above natural background (^{90}Sr)		BNA 2001
	Occupational	S1x10^{-9} µCi/mL I 5x10^{-9} µCi/mL	
	Non occupational	S3x10^{-11} µCi/mL I 2x10^{-10} µCi/mL	
Illinois	Concentrations in air above natural background	S3x10^{-11} µCi/mL I 2x10^{-10} µCi/mL	BNA 2001
New Jersey	Maximum permissible average concentrations of radioactive materials in air (^{85m}Sr)		BNA 2001
	Occupational	S4x10^{-5} µCi/mL I 3x10^{-5} µCi/mL	
	Non occupational	S1x10^{-6} µCi/mL I 1x10^{-6} µCi/mL	
b. Water			
Alabama	Drinking water guidelines	8 pCi/L	HSDB 2001
Alaska	MCL for drinking water (^{90}Sr)	8 pCi/L	ADEC 2000
Arkansas	Concentrations in water above natural background (^{90}Sr)		BNA 2001
	Occupational	S1x10^{-5} µCi/mL I 1x10^{-3} µCi/mL	
	Non occupational	S3x10^{-7} µCi/mL I 4x10^{-5} µCi/mL	
California	Drinking water guidelines	8 pCi/L	HSDB 2001
	Primary MCL (^{90}Sr)	8 pCi/L	CA Department of Health Services 2000
Colorado	Standards applicable to surface waters	8 pCi/L	BNA 2001
	Groundwater quality standards	8 pCi/L	BNA 2001
Connecticut	Drinking water guidelines	8 pCi/L	HSDB 2001
Florida	Drinking water guidelines	4,200 µg/L	HSDB 2001
	MCL for groundwater (^{90}Sr)	8 pCi/L	FL DEP 2000
Idaho	Primary constituent standards for groundwater (^{90}Sr)	8 pCi/L	ID Department of Health & Welfare 1999
Illinois	Drinking water guidelines	8 pCi/L	HSDB 2001
	Water quality standard (^{90}Sr)	1 and 2 pCi/L	IL Environmental Protection Agency 1999

Table 8-2. Regulations and Guidelines Applicable to Radioactive Strontium

Agency	Description	Information	Reference
STATE (*cont.*)			
New Jersey	Maximum permissible average concentrations of radioactive materials in water (^{85m}Sr)		BNA 2001
	Occupational	S0.2 µCi/mL I 0.2 µCi/mL	
	Non occupational	S0.007 µCi/mL I 0.007 µCi/mL	
Indiana	Maximum contaminant levels in community water systems; average annual concentrations assumed to produce a total body or organ dose of 4 millirem/year		IN General Assembly 2000
	^{90}Sr	8 pCi/L	
	Critical organ	Bone marrow	
Maine	Drinking water guidelines	2,400 µg/L	HSDB 2001
Michigan	Maximum contaminant levels in community water systems; average annual concentrations assumed to produce a total body or organ dose of 4 millirem/year		MDEQ 2000
	^{90}Sr	8 pCi/L	
	Critical organ	Bone marrow	
New Hampshire	Drinking water guidelines	8 pCi/L	HSDB 2001
Wisconsin	Drinking water guidelines	8 pCi/L	HSDB 2001
c. Food		No data	
d. Other			
Arkansas	Determination of A_1 and A_2 quantities (^{90}Sr)		BNA 2001
	A_1	10 Ci	
	A_2	0.4 Ci	
	Specific gravity	$1.5x10^2$ Ci/g	
	Standard for protection against radiation	0.1 µCi	BNA 2001
Colorado	Determination of A_1 and A_2 (^{90}Sr)		BNA 2001
	A_1	5.41 Ci	
	A_2	2.70 Ci	
Delaware	Average annual concentration assumed to produce a total body or organ dose of 4 rem/year (^{90}Sr)		BNA 2001
	Critical organ (bone marrow)	8 pCi/L	
Nevada	Quantities of radioactive material for signs, labels, and signals	0.1 µCi	BNA 2001

Table 8-2. Regulations and Guidelines Applicable to Radioactive Strontium

Agency	Description	Information	Reference

[a]The limits apply to the sum of the relevant doses from external exposure in the specified period and the 50-year committed dose (to age 70 years for children) from intakes in the same period.
[b]With the further provision that the effective dose should not exceed 50 mSv in any single year. Additional restrictions apply to the occupational exposure of pregnant women.
[c]The limitation on the effective dose provides sufficient protection for the skin against stochastic effects. An additional limit is needed for localized exposures in order to prevent deterministic effects.
[d]Group 1: human carcinogen
[e]In special circumstances, a higher value of effective dose could be allowed in a single year, provided that the average over 5 years does not exceed 1 mSv per year.
[f]Class D: all soluble compounds except SrTiO
[g]Class Y: all insoluble compounds and SrTiO
[h]Class D: refers to materials with retention times in the pulmonary region of <10 days
[i]Class W: refers to materials with retention times in the pulmonary region of 10–100 days
[j]Class Y: refers to materials with retention times in the pulmonary region of >100 days
[k]Release limit per 1,000 metric tons of heavy metal (MTHM) or other unit of waste
[l]Column 1: The sum of the fractions rule for mixtures of radionuclides. For determining classification for waste that contains a mixture of radionuclides, it is necessary to determine the sum of fractions by dividing each nuclide's concentration by the appropriate limit and adding the resulting values. The appropriate limits must all be taken from the same column of the same table. The sum of the fractions for the column must be less than 1.0 if the waste class is to be determined by the column. Example: A waste contains ^{90}Sr in a concentration of 50 Ci/m^3 and ^{137}Cs of 22 Ci/m^3. Since the concentrations both exceed the values in Column 1, Table 2, they must be compared to Column 2 values. For ^{90}Sr fraction 50/150=0.33; for ^{137}Cs fraction, 22/44=0.5; the sum of the fractions=0.83. Since the sum is less than 1.0, the waste is Class B.
[m]Group A: human carcinogen
[n]Derived intervention levels (DIL) are concentrations of radioactivity in food whose consumption would deliver a committed effective dose equivalent equal to the most limiting of the protection action guides (PAGs) developed by FDA (1998).
[o]The FDA-recommended Derived Intervention Level (DIL) for radionuclides of ^{89}Sr, is defined as the DIL for the most sensitive age group (3 months) that was calculated from the most limiting Protective Action Goal (PAG; 50 mSv committed dose equivalent to the bone).
[p]The FDA-recommended Derived Intervention Level (DIL) for radionuclides of ^{90}Sr, is defined as the DIL for the most sensitive age group (15 years) that was calculated from the most limiting Protective Action Goal (PAG; 50 mSv committed dose equivalent to the bone).
[q]Radioactive slope factors calculated by EPA's Office of Radiation and Indoor Air (ORIA). Slope factors are central estimates in a linear model of the age-averaged, lifetime attributable radiation cancer incidence (fatal and nonfatal cancer) risk per unit of activity ingested, expressed as risk per picocurie (pCi).
[r]Inhalation slope factors are central estimates in a linear model of the age-average, lifetime attributable radiation cancer incidence (fatal and nonfatal cancer) risk per unit of activity inhaled, expressed as risk per picocurie (pCi).
[s]External slope factors are central estimates of the lifetime attributable radiation cancer incidence risk for each year of exposure to external radiation from photon-emitting radionuclides distributed uniformly in a thick layer of soil, expressed as risk/year per pCu per gram of soil.
[t]Sum of external and internal exposures but excluding doses from natural sources.

ACGIH = American Conference of Governmental Industrial Hygienists; ADEC = Alaska Department of Environmental Conservation; ALI = annual limits on intake; BNA = Bureau of National Affairs; CFR = Code of Federal Regulations; DAC = derived air concentration; DEP = Department of Environmental Protection; DOE = Department of Energy; DOT = Department of Transportation; EPA = Environmental Protection Agency; FDA = Food and Drug Administration; HSDB = Hazardous Substances Data Bank; I = insoluble; IARC = International Agency for Research on Cancer; ICRP = International Commission on Radiological Protection; MCL = maximum contaminant level; MCLG = maximum contaminant level goal; MDEQ = Michigan Department of Environmental Quality; mSv = millisievert; MTHM = metric tons of heavy metal; NCRP = National Council on Radiation Protection; NIOSH = National Institute for Occupational Safety and Health; USNRC = Nuclear Regulatory Commission; OSHA = Occupational Safety and Health Administration; PAG = protective action guide; REL = recommended exposure limit; S = soluble; TWA = time-weighted average

Table 8-3. Effective Dose Coefficients[a] (e(50)) and Annual Limits on Intake[b] (ALI) for Occupational Exposures to Radioactive Strontium Isotopes

Radio-nuclide			Inhalation, 1μm AMAD[c]			Inhalation, 5μm AMAD			Ingestion		
Half-life	Absorp-tion type	f1[d]	e_{inh} (50)	ALI (Bq)	ALI (mCi)	e_{inh} (50)	ALI (Bq)	ALI (mCi)	e_{ing} (50)	ALI (Bq)	ALI (mCi)
^{80}Sr											
1.67 hr	fast	0.3	7.6×10^{-11}	2.6×10^{8}	7.11	1.3×10^{-10}	1.5×10^{8}	4.158	3.4×10^{-10}	5.9×10^{7}	1.590
	slow	0.01	1.4×10^{-10}	1.4×10^{8}	3.86	2.1×10^{-10}	9.5×10^{7}	2.574	3.5×10^{-10}	5.7×10^{7}	1.544
^{81}Sr											
0.425 hr	fast	0.3	2.2×10^{-11}	9.1×10^{8}	24.57	3.9×10^{-11}	5.1×10^{8}	13.860	7.7×10^{-11}	2.6×10^{8}	7.020
	slow	0.01	3.8×10^{-11}	5.3×10^{8}	14.22	6.1×10^{-11}	3.3×10^{8}	8.861	7.8×10^{-11}	2.6×10^{8}	6.93
^{82}Sr											
25.0 d	fast	0.3	2.2×10^{-9}	9.1×10^{6}	0.245	3.3×10^{-9}	6.1×10^{6}	0.164	6.1×10^{-9}	3.3×10^{6}	0.089
	slow	0.01	1.0×10^{-8}	2.0×10^{6}	0.054	7.7×10^{-9}	2.6×10^{6}	0.070	6.0×10^{-9}	3.3×10^{6}	0.090
^{83}Sr											
1.35 d	fast	0.3	1.7×10^{-10}	1.2×10^{8}	3.179	3.0×10^{-10}	6.7×10^{7}	1.801	4.9×10^{-10}	4.1×10^{7}	1.103
	slow	0.01	3.4×10^{-10}	5.9×10^{7}	1.589	4.9×10^{-10}	4.1×10^{7}	1.103	5.8×10^{-10}	3.5×10^{7}	0.932
^{85}Sr											
64.8 d	fast	0.3	3.9×10^{-10}	5.1×10^{7}	1.386	5.6×10^{-10}	3.6×10^{7}	0.965	5.6×10^{-10}	3.6×10^{7}	0.965
	slow	0.01	7.7×10^{-10}	2.6×10^{7}	0.702	6.4×10^{-10}	3.1×10^{7}	0.845	3.3×10^{-10}	6.1×10^{7}	1.638
^{85m}Sr											
1.16 hr	fast	0.3	3.1×10^{-12}	6.5×10^{9}	174.00	5.6×10^{-12}	3.6×10^{9}	96.53	6.1×10^{-12}	3.3×10^{9}	88.61
	slow	0.01	4.5×10^{-12}	4.4×10^{9}	120.00	7.4×10^{-12}	2.7×10^{9}	73.05	6.1×10^{-12}	3.3×10^{9}	88.61
^{87m}Sr											
2.8 hr	fast	0.3	1.2×10^{-11}	1.7×10^{9}	45.05	2.2×10^{-11}	9.1×10^{8}	24.57	3.0×10^{-11}	6.7×10^{8}	18.02
	slow	0.01	2.2×10^{-11}	9.1×10^{8}	24.57	3.5×10^{-11}	5.7×10^{8}	15.44	3.3×10^{-11}	6.1×10^{8}	16.38
^{89}Sr											
50.5 d	fast	0.3	1.0×10^{-9}	2.0×10^{7}	0.540	1.4×10^{-9}	1.4×10^{7}	0.386	2.6×10^{-9}	7.7×10^{6}	0.208
	slow	0.01	7.5×10^{-9}	2.7×10^{6}	0.072	5.6×10^{-9}	3.6×10^{6}	0.097	2.3×10^{-9}	8.7×10^{6}	0.235
^{90}Sr											
29.1 yr	fast	0.3	2.4×10^{-8}	8.3×10^{5}	0.023	3.0×10^{-8}	6.7×10^{5}	0.018	2.8×10^{-8}	7.1×10^{5}	0.019
	slow	0.01	1.5×10^{-7}	1.3×10^{5}	0.004	7.7×10^{-8}	2.6×10^{5}	0.007	2.7×10^{-9}	7.4×10^{6}	0.200
^{91}Sr											
9.5 hr	fast	0.3	1.7×10^{-10}	1.2×10^{8}	3.180	2.9×10^{-10}	6.9×10^{7}	1.864	6.5×10^{-10}	3.1×10^{7}	0.832
	slow	0.01	4.1×10^{-10}	4.9×10^{7}	1.318	5.7×10^{-10}	3.5×10^{7}	0.948	7.6×10^{-10}	2.6×10^{7}	0.711
^{92}Sr											
2.7 hr	fast	0.3	1.1×10^{-10}	1.8×10^{8}	4.914	1.8×10^{-10}	1.1×10^{8}	3.003	4.3×10^{-10}	4.7×10^{7}	1.257
	slow	0.01	2.3×10^{-10}	8.7×10^{7}	2.350	3.4×10^{-10}	5.9×10^{7}	1.590	4.9×10^{-10}	4.1×10^{7}	1.103

[a]ICRP (1994)
[b]For internal exposures, ICRP (1994) recommends an effective dose limit of 100 mSv over 5 years (averaging 20 mSv per year). The Annual Limits on Intake (ALI in Bequerels) were calculated by dividing the annual effective dose limit (0.02 Sv) by the dose coefficient (e(50)) in Sieverts/Bequerel.
[c]ICRP (1994) calculated inhalation dose coefficients for particles with AMAD of 1 or 5 μm.
[d]Fractional absorption factor used by ICRP (1994: Annexes E and F) to calculate effective dose coefficients. A value of 0.3 was used for unspecified strontium compounds and 0.01 was used for strontium titanate.

ALI = Annual Limits on Intake; AMAD = Activity Median Average Diameters; Bq = Bequerels; Ci = Curies; d = day; hr = hour; yr = year

groups and 14 radiogenic cancer cites (EPA 2000e). These factors are used to calculate the lifetime excess total cancer risk per unit intake or exposure to radiation (under the different exposure scenarios). Slope factors for radioactive strontium isotopes are listed in Table 8-2. IARC has determined that all internally deposited beta emitters, including radioactive strontium, are carcinogenic to humans and has assigned them to Group 1 (IARC 2001, 2002b).

Because of the potential for ionizing radiation to cause deterministic (acute radiation syndrome) and nondeterministic (cancer) health effects in exposed individuals, safe dose guidelines and regulations have been established for radionuclides in air and water by a number of international and national agencies (Tables 8-2 and 8-3). Regulations and guidelines that protect against deterministic effects are based on identified acute thresholds doses for those effects, with a reduction to protect sensitive populations and provide safety margins to account for uncertainties. Those that protect against nondeterministic effects use the observed frequencies with which those effects occur at high doses, account for uncertainties that may exist, and assume a linear dose-effect relationship to calculate the doses at which the effects would be presumed to occur at some acceptable frequency, such as the range of 10^{-4}–$10^{-}6$, which EPA often considers. This proportionality assumes a linear no threshold (LNT) dose effect curve. During the last decade, there have been reductions in LNT-based public radiation dose limits and site cleanup levels that have increased the scope and cost of medical, occupational, and environmental radiation protection efforts. Some recent studies found a reduction in health effects when the dose was delivered at lower dose rates, indicating a potential application to future protection guidelines and regulations.

The International Commission on Radiological Protection (ICRP) provides guidance on the fundamental principles regarding the biological effects of exposure to ionizing radiation and recommends exposure limits based on these analyses. In the United States, the National Council on Radiation Protection and Measurements (NCRP) was chartered in 1964 by the U.S. Congress to: (1) disseminate information of public interest and recommend radiation levels to protect the public, (2) support cooperation among organizations concerned with radiation protection, (3) develop basic concepts about radiation protection, and (4) cooperate with the ICRP and the International Commission on Radiation Units and Measurements. Even though the NCRP is a nongovernmental organization, it provides recommendations that guide the establishment of federal radiation policies, agency requirements, and statutory laws. Through the governmental agencies that rely on NCRP recommendations, the work of this organization has a significant impact on the many activities in the United States involving the use of radiation and radioactive materials.

The EPA sets radiation safety policy and basic safety standards. The execution of this policy is assigned to the various regulatory agencies, including the EPA itself, for application to the specific activities that they regulate. The U.S. Nuclear Regulatory Commission (USNRC), an independent government agency, regulates commercial nuclear power reactors; research/test/training reactors; fuel cycle facilities; and the transport, storage, and disposal of nuclear materials and waste (USNRC 1997). The EPA is responsible for protecting the public and the environment and for cleanup of radioactively contaminated sites (EPA 1997a).

The Food and Drug Administration (FDA) develops standards for radioactive material concentrations in food (FDA 1998) and in medical devices used in radiation therapy (FDA 1997). The FDA recently updated its guidance document that presents recommended action levels for accidental radioactive contamination of foods, both domestic and imported (FDA 1998). These derived intervention levels (DILs) are estimated levels in food that could lead to individuals receiving a radiation equivalent dose equal to the FDA protection action guide (PAG) that is set as the more limiting of either 0.5 rem (5 mSv) for committed effective dose or 5 rem (50 mSv) committed dose equivalent to any individual tissue or organ. Derived intervention levels, which are based on food intake rates, are calculated for different age groups and the DIL for the most vulnerable group is then adopted to provide a conservative margin of safety for the entire population. For ^{90}Sr, with a half-life of 29 years, the DIL is based on the dose to the bone surface in 15-year-old individuals, who have the highest rate of bone growth. For ^{89}Sr, with a half-life of 50.5 days, 3-month-old infants represent the most sensitive group because of the higher doses to the lower intestine from milk consumption. Table 8-2 presents the DILs adopted for the two strontium isotopes.

Transport of radioactive materials is regulated by the Department of Transportation (DOT) in conjunction with the USNRC. Coordinating government emergency response to accidents involving radioactive materials is the responsibility of the Federal Emergency Management Administration (FEMA).

National regulations governing the occupational exposure to ionizing radiation include USNRC regulations (10 CFR 20), the Occupational Safety and Health Administration (OSHA) standards for ionizing radiation (29 CFR 1910.1096), and the Department of Energy (DOE) standards for occupational radiation protection (10 CFR 835). National regulations concerning general population exposure to radiation have been developed as proposed by the EPA and as finalized by the USNRC based on the dose limit recommendations of the ICRP (ICRP 1996) and the NCRP (NCRP 1993). The EPA and USNRC

also use the BEIR reports of the National Academy of Sciences and the UNSCEAR reports on biological effects to help develop the U.S. standards in line with the NCRP and the ICRP consensus standards.

Currently, there are 29 "NRC Agreement States." An agreement state is any state that has entered into an agreement with the USNRC under Section 274 of the Atomic Energy Act of 1954, as amended. The USNRC relinquishes to these states the majority of its regulatory authority over source, by-product, and special nuclear material in quantities not sufficient to form a critical mass. However, the regulation of nuclear reactors is under USNRC jurisdiction. In the remaining states, USNRC still handles all of the inspection, enforcement, and licensing responsibilities.

The basic philosophy of radiation safety is to minimize unnecessary radiation exposure. The specific objectives of radiation safety guidance as stated by NCRP are (1) to prevent the occurrence of severe radiation-induced deterministic (nonstochastic) disease, and (2) to limit the risk of the nondeterministic (stochastic) effects (fatal cancer and genetic effects) to a reasonable level compared with nonradiation risks and in relation to societal needs, benefits gained, and economic factors. In addition to regulations that set upper limits on radiation dose, the concept of ALARA (As Low As Reasonably Achievable) was introduced to ensure that workplace endeavors resulting in exposures to radiation provide sufficient benefits that offset any potential detriment they cause (ACGIH 2002). The goal is not to eliminate all radiation exposure, which would not be possible, but instead to strive for an appropriate balance between protection of public health and reasonable costs (economic, social, etc.) while maintaining desirable dose limits. The ACGIH has adopted the occupational exposure guidance of the ICRP (ACGIH 2002).