Radiological Risk Assessment for a Large Combined Sanitary/Storm Sewer and Wastewater Treatment Plant

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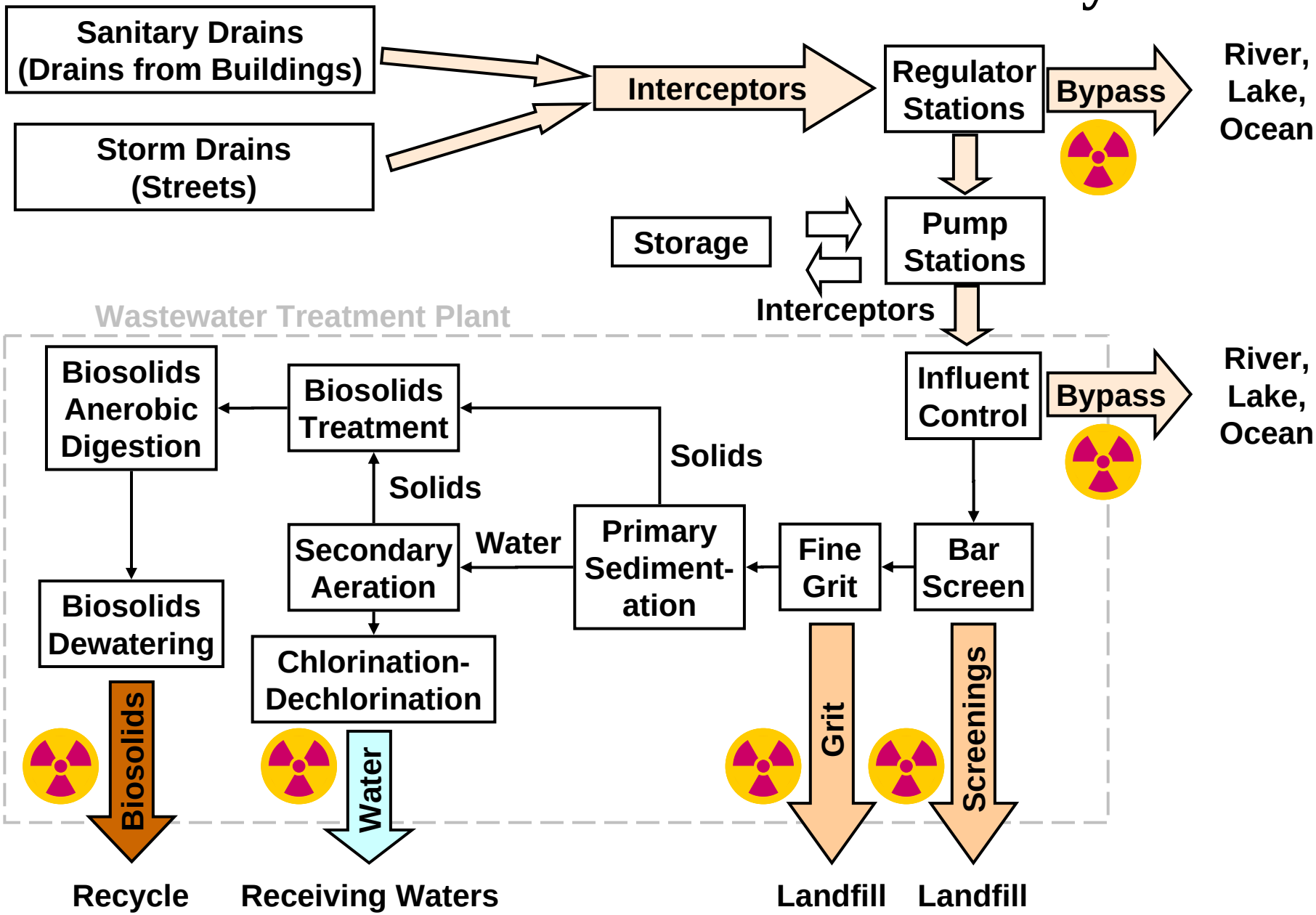
Outline

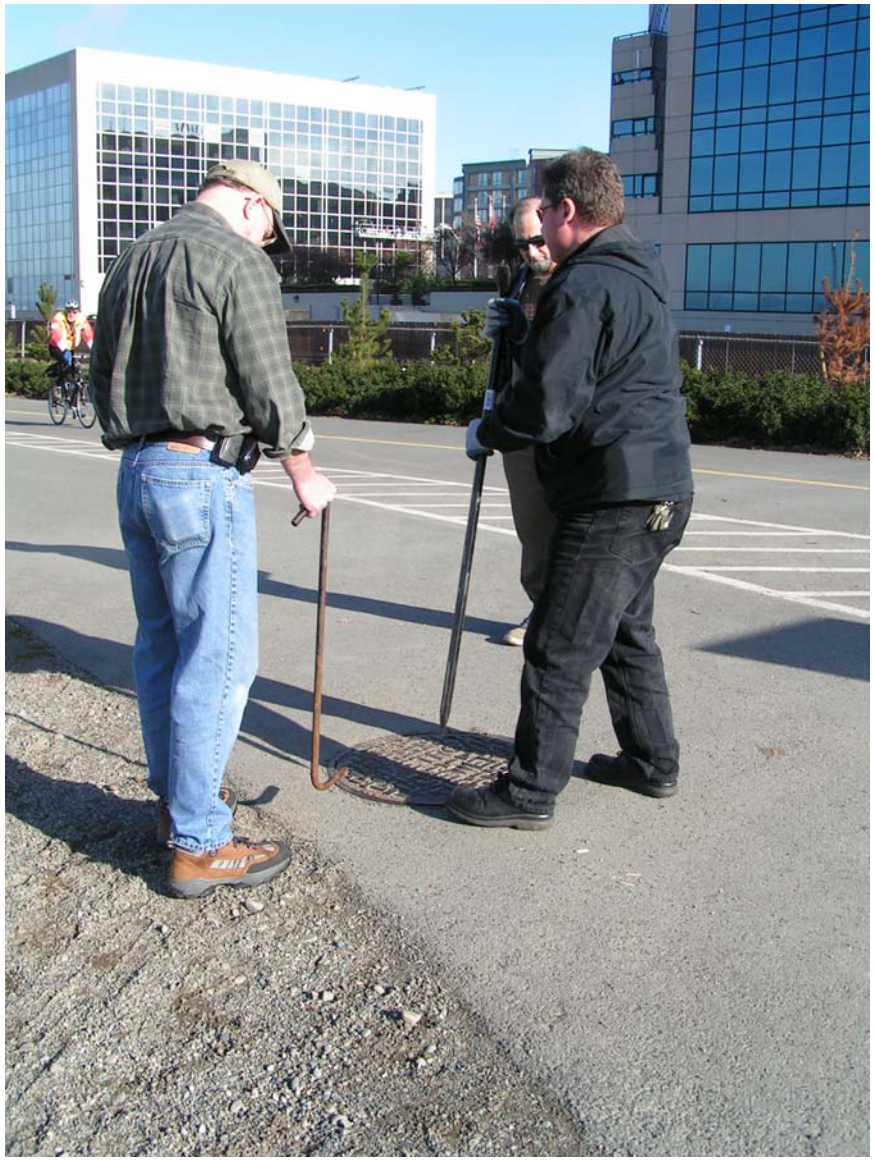
- Wastewater Treatment 101
- Radiological risk assessment
- Radiological instrumentation assessment
- Unresolved issues and opportunities

A Combined Sanitary and Storm Sewer System: King County's West Point Treatment Plant

Combined Wastewater Treatment System



Sewer Lines Are Generally Buried



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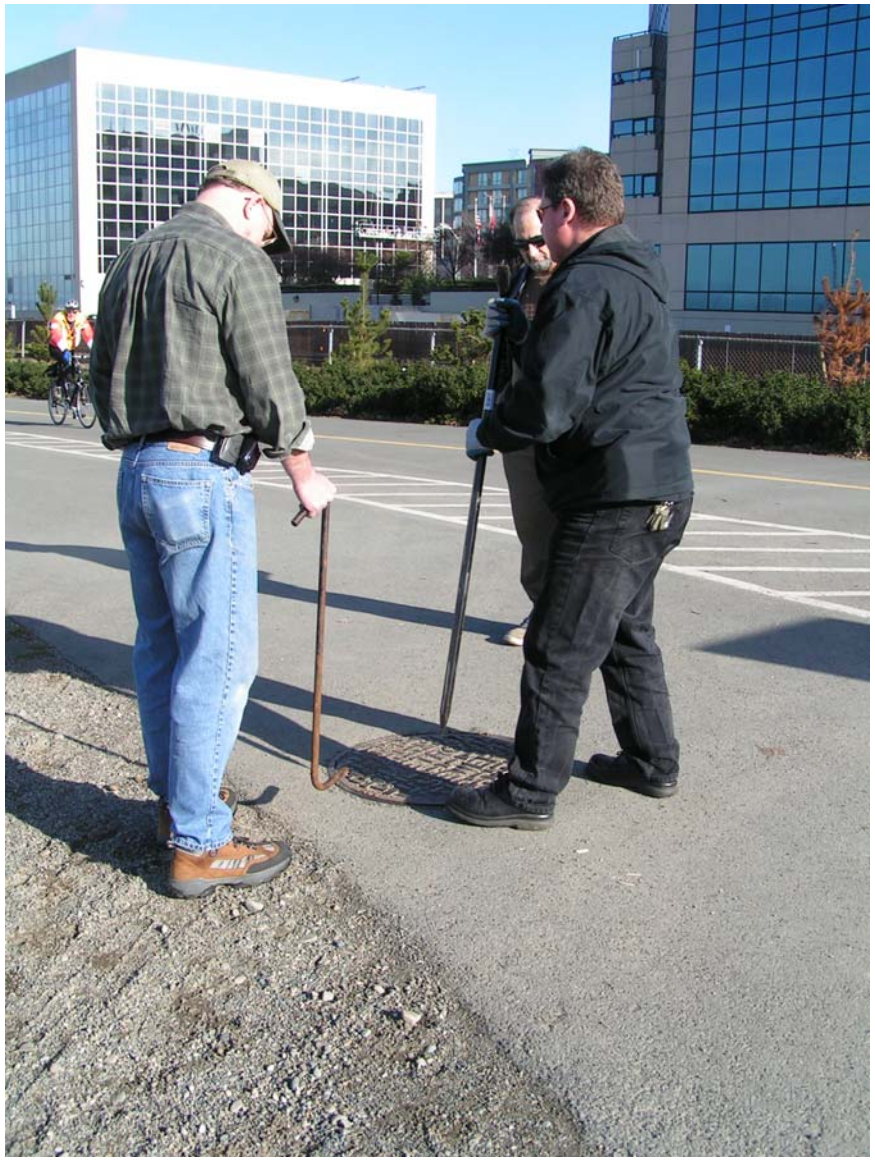


Pump Station

Wet Well at Pump Station

Combs Clear Debris from Bar Screens

Screenings Go to a Dumpster

mm- to cm-sized Grit

Secondary Clarifier

After Leaving Anaerobic Digestion, Biosolids Are Concentrated

Concentrated Biosolids Are Collected for Shipment

4-5 48 Tonne (105,000 lb.) Biosolids Trucks/Day

- Biosolids shipped east for agricultural application

Agricultural Application of Biosolids

Photo courtesy Michael A. Smith

PERIODIC TABLE

Atomic Properties of the Elements

NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

Physics Laboratory
physics.nist.gov

Standard Reference Data Group
www.nist.gov/srd

Frequently used fundamental physical constants

For the most accurate values of these and other constants, visit physics.nist.gov/constants

1 second = 9 192 631 770 periods of radiation corresponding to the transition between the two hyperfine levels of the ground state of ^{133}Cs

speed of light in vacuum	c	299 792 458 m s^{-1}	(exact)
Planck constant	h	6.6261×10^{-34} J s	($\hbar = h/2\pi$)
elementary charge	e	1.6022×10^{-19} C	
electron mass	m_e	9.1094×10^{-31} kg	
	$m_e c^2$	0.5110 MeV	
proton mass	m_p	1.6726×10^{-27} kg	
fine-structure constant	α	1/137.036	
Rydberg constant	R_∞	10 973 732 m^{-1}	
	$R_\infty c$	$3.289\,842 \times 10^{15}$ Hz	
	$R_\infty hc$	13.6057 eV	
Boltzmann constant	k	1.3807×10^{-23} J K^{-1}	

Solids
Liquids
Gases
Artificially Prepared

Period	Group 1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIII	9 VIII	10 VIII	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 $^2S_{1/2}$ **H** Hydrogen 1.00794 $1s$ 13.5984																	2 $^1S_0$ **He** Helium 4.002602 $1s^2$ 24.5874
2	3 $^2S_{1/2}$ **Li** Lithium 6.941 $1s^2 2s$ 5.3917	4 $^1S_0$ **Be** Beryllium 9.012182 $1s^2 2s^2$ 9.3227											5 $^2P^\circ_{1/2}$ **B** Boron 10.811 $1s^2 2s^2 2p$ 8.2980	6 $^3P_0$ **C** Carbon 12.0107 $1s^2 2s^2 2p^2$ 11.2603	7 $^4S^\circ_{3/2}$ **N** Nitrogen 14.0067 $1s^2 2s^2 2p^3$ 14.5341	8 $^3P_2$ **O** Oxygen 15.9994 $1s^2 2s^2 2p^4$ 13.6181	9 $^2P^\circ_{3/2}$ **F** Fluorine 18.9984032 $1s^2 2s^2 2p^5$ 17.4228	10 $^1S_0$ **Ne** Neon 20.1797 $1s^2 2s^2 2p^6$ 21.5645
3	11 $^2S_{1/2}$ **Na** Sodium 22.989770 [Ne]$3s$ 5.1391	12 $^1S_0$ **Mg** Magnesium 24.3050 [Ne]$3s^2$ 7.6462											13 $^2P^\circ_{1/2}$ **Al** Aluminum 26.981538 [Ne]$3s^2 3p$ 5.9858	14 $^3P_0$ **Si** Silicon 28.0855 [Ne]$3s^2 3p^2$ 8.1517	15 $^4S^\circ_{3/2}$ **P** Phosphorus 30.973761 [Ne]$3s^2 3p^3$ 10.4867	16 $^3P_2$ **S** Sulfur 32.065 [Ne]$3s^2 3p^4$ 10.3600	17 $^2P^\circ_{3/2}$ **Cl** Chlorine 35.453 [Ne]$3s^2 3p^5$ 12.9676	18 $^1S_0$ **Ar** Argon 39.948 [Ne]$3s^2 3p^6$ 15.7596
4	19 $^2S_{1/2}$ **K** Potassium 39.0983 [Ar]$4s$ 4.3407	20 $^1S_0$ **Ca** Calcium 40.078 [Ar]$4s^2$ 6.1132	21 $^2D_{3/2}$ **Sc** Scandium 44.955910 [Ar]$3d4s^2$ 6.5615	22 $^3F_2$ **Ti** Titanium 47.867 [Ar]$3d^2 4s^2$ 6.8281	23 $^4F_{3/2}$ **V** Vanadium 50.9415 [Ar]$3d^3 4s^2$ 6.7462	24 $^7S_3$ **Cr** Chromium 51.9961 [Ar]$3d^5 4s$ 6.7665	25 $^6S_{5/2}$ **Mn** Manganese 54.938049 [Ar]$3d^5 4s^2$ 7.4340	26 $^5D_4$ **Fe** Iron 55.845 [Ar]$3d^6 4s^2$ 7.9024	27 $^4F_{9/2}$ **Co** Cobalt 58.933200 [Ar]$3d^7 4s^2$ 7.8810	28 $^3F_4$ **Ni** Nickel 58.6934 [Ar]$3d^8 4s^2$ 7.6398	29 $^2S_{1/2}$ **Cu** Copper 63.546 [Ar]$3d^{10} 4s$ 7.7264	30 $^1S_0$ **Zn** Zinc 65.409 [Ar]$3d^{10} 4s^2$ 9.3942	31 $^2P^\circ_{1/2}$ **Ga** Gallium 69.723 [Ar]$3d^{10} 4s^2 4p$ 5.9993	32 $^3P_0$ **Ge** Germanium 72.64 [Ar]$3d^{10} 4s^2 4p^2$ 7.8994	33 $^4S^\circ_{3/2}$ **As** Arsenic 74.92160 [Ar]$3d^{10} 4s^2 4p^3$ 9.7886	34 $^3P_2$ **Se** Selenium 78.96 [Ar]$3d^{10} 4s^2 4p^4$ 9.7524	35 $^2P^\circ_{3/2}$ **Br** Bromine 79.904 [Ar]$3d^{10} 4s^2 4p^5$ 11.8138	36 $^1S_0$ **Kr** Krypton 83.798 [Ar]$3d^{10} 4s^2 4p^6$ 13.9996
5	37 $^2S_{1/2}$ **Rb** Rubidium 85.4678 [Kr]$5s$ 4.1771	38 $^1S_0$ **Sr** Strontium 87.62 [Kr]$5s^2$ 5.6949	39 $^2D_{3/2}$ **Y** Yttrium 88.90585 [Kr]$4d5s^2$ 6.2173	40 $^3F_2$ **Zr** Zirconium 91.224 [Kr]$4d^2 5s^2$ 6.6339	41 $^6D_{1/2}$ **Nb** Niobium 92.90638 [Kr]$4d^4 5s$ 6.7589	42 $^7S_3$ **Mo** Molybdenum 95.94 [Kr]$4d^5 5s$ 7.0924	43 $^6S_{5/2}$ **Tc** Technetium (98) [Kr]$4d^5 5s^2$ 7.28	44 $^5F_5$ **Ru** Ruthenium 101.07 [Kr]$4d^7 5s$ 7.3605	45 $^4F_{9/2}$ **Rh** Rhodium 102.90550 [Kr]$4d^8 5s$ 7.4589	46 $^1S_0$ **Pd** Palladium 106.42 [Kr]$4d^{10}$ 8.3369	47 $^2S_{1/2}$ **Ag** Silver 107.8682 [Kr]$4d^{10} 5s$ 7.5762	48 $^1S_0$ **Cd** Cadmium 112.411 [Kr]$4d^{10} 5s^2$ 8.9938	49 $^2P^\circ_{1/2}$ **In** Indium 114.818 [Kr]$4d^{10} 5s^2 5p$ 5.7864	50 $^3P_0$ **Sn** Tin 118.710 [Kr]$4d^{10} 5s^2 5p^2$ 7.3439	51 $^4S^\circ_{3/2}$ **Sb** Antimony 121.760 [Kr]$4d^{10} 5s^2 5p^3$ 8.6084	52 ^3P **Te** Tellurium 127.60 [Kr]$4d^{10} 5s^2 5p^4$ 9.0096	53 $^2P^\circ_{3/2}$ **I** Iodine 126.90447 [Kr]$4d^{10} 5s^2 5p^5$ 10.4513	54 $^1S_0$ **Xe** Xenon 131.293 [Kr]$4d^{10} 5s^2 5p^6$ 12.1298
6	55 $^2S_{1/2}$ **Cs** Cesium 132.90545 [Xe]$6s$ 3.8939	56 $^1S_0$ **Ba** Barium 137.327 [Xe]$6s^2$ 5.2117	72 $^3F_2$ **Hf** Hafnium 178.49 [Xe]$4f^{14} 5d^2 6s^2$ 6.8251	73 $^4F_{3/2}$ **Ta** Tantalum 180.9479 [Xe]$4f^{14} 5d^3 6s^2$ 7.5496	74 $^5D_0$ **W** Tungsten 183.84 [Xe]$4f^{14} 5d^4 6s^2$ 7.8640	75 $^6S_{5/2}$ **Re** Rhenium 186.207 [Xe]$4f^{14} 5d^5 6s^2$ 7.8335	76 $^5D_4$ **Os** Osmium 190.23 [Xe]$4f^{14} 5d^6 6s^2$ 8.4382	77 $^4F_{9/2}$ **Ir** Iridium 192.217 [Xe]$4f^{14} 5d^7 6s^2$ 8.9670	78 $^3D_3$ **Pt** Platinum 195.078 [Xe]$4f^{14} 5d^9 6s$ 8.9588	79 $^2S_{1/2}$ **Au** Gold 196.96655 [Xe]$4f^{14} 5d^{10} 6s$ 9.2255	80 $^1S_0$ **Hg** Mercury 200.59 [Xe]$4f^{14} 5d^{10} 6s^2$ 10.4375	81 $^2P^\circ_{1/2}$ **Tl** Thallium 204.3833 [Hg]$6p$ 6.1082	82 $^3P_0$ **Pb** Lead 207.2 [Hg]$6p^2$ 7.4167	83 $^4S^\circ_{3/2}$ **Bi** Bismuth 208.98038 [Hg]$6p^3$ 7.2855	84 $^3P_2$ **Po** Polonium (209) [Hg]$6p^4$ 8.414	85 $^2P^\circ_{3/2}$ **At** Astatine (210) [Hg]$6p^5$	86 $^1S_0$ **Rn** Radon (222) [Hg]$6p^6$ 10.7485
7	87 $^2S_{1/2}$ **Fr** Francium (223) [Rn]$7s$ 4.0727	88 $^1S_0$ **Ra** Radium (226) [Rn]$7s^2$ 5.2784	104 $^3F_2$? **Rf** Rutherfordium (261) [Rn]$5f^{14} 6d^2 7s^2$? 6.0 ?	105 **Db** Dubnium (262)	106 **Sg** Seaborgium (266)	107 **Bh** Bohrium (264)	108 **Hs** Hassium (277)	109 **Mt** Meitnerium (268)	110 **Uun** Ununnilium (281)	111 **Uuu** Unununium (272)	112 **Uub** Ununbium (285)			114 **Uuq** Ununquadium (289)		116 **Uuh** Ununhexium (292)		

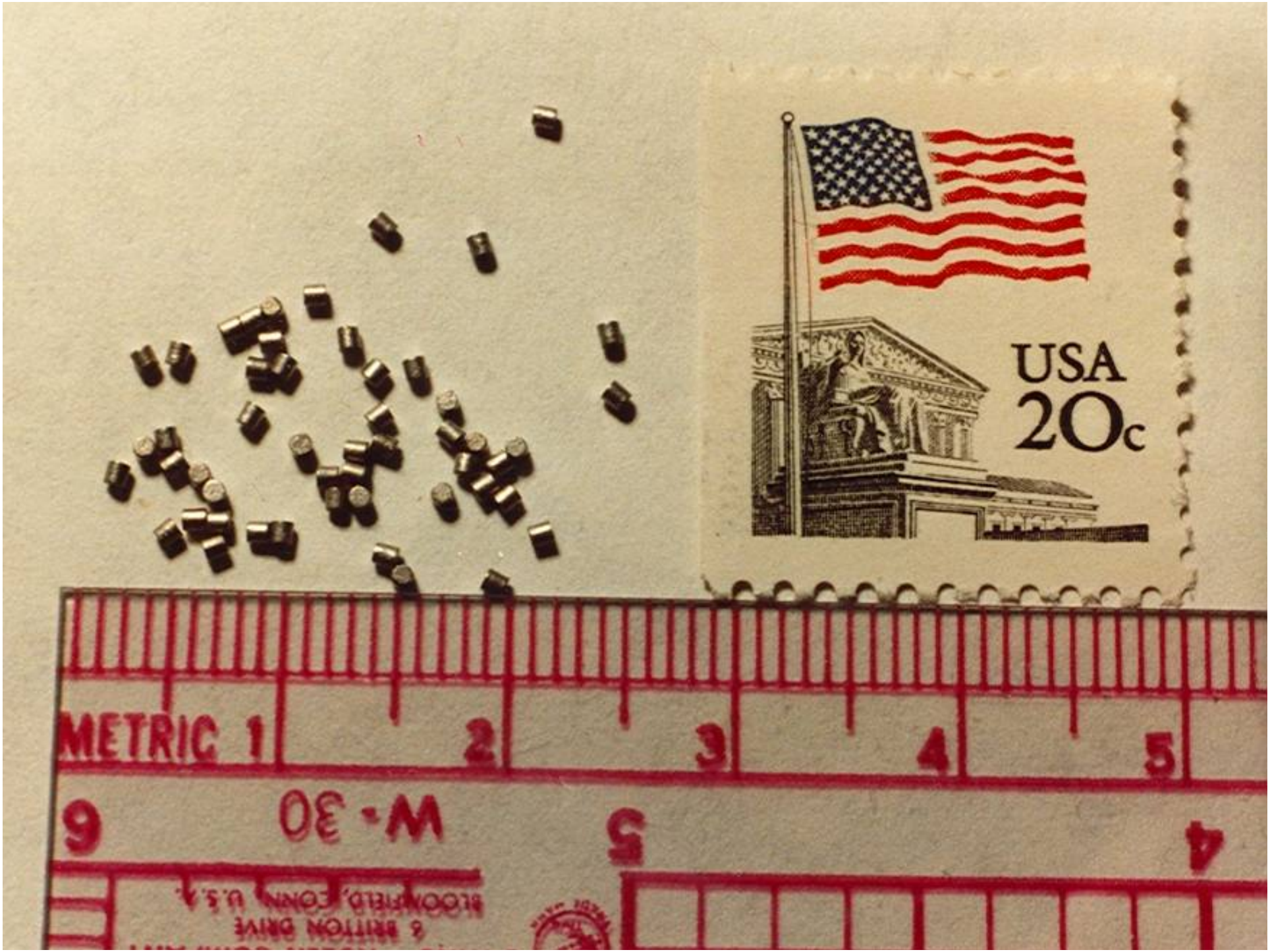
Lanthanides	57 $^2D_{3/2}$ **La** Lanthanum 138.9055 [Xe]$5d6s^2$ 5.5769	58 $^1G^\circ_4$ **Ce** Cerium 140.116 [Xe]$4f5d6s^2$ 5.5387	59 $^4I^\circ_{9/2}$ **Pr** Praseodymium 140.90765 [Xe]$4f^3 6s^2$ 5.473	60 $^5I_4$ **Nd** Neodymium 144.24 [Xe]$4f^4 6s^2$ 5.5250	61 $^6H^\circ_{5/2}$ **Pm** Promethium (145) [Xe]$4f^5 6s^2$ 5.582	62 $^7F_0$ **Sm** Samarium 150.36 [Xe]$4f^6 6s^2$ 5.6437	63 $^8S^\circ_{7/2}$ **Eu** Europium 151.964 [Xe]$4f^7 6s^2$ 5.6704	64 $^9D^\circ_2$ **Gd** Gadolinium 157.25 [Xe]$4f^7 5d6s^2$ 6.1498	65 $^6H^\circ_{15/2}$ **Tb** Terbium 158.92534 [Xe]$4f^9 6s^2$ 5.8638	66 $^5I_8$ **Dy** Dysprosium 162.500 [Xe]$4f^{10} 6s^2$ 5.9389	67 $^4I^\circ_{15/2}$ **Ho** Holmium 164.93032 [Xe]$4f^{11} 6s^2$ 6.0215	68 $^3H_6$ **Er** Erbium 167.259 [Xe]$4f^{12} 6s^2$ 6.1077	69 $^2F^\circ_{7/2}$ **Tm** Thulium 168.93421 [Xe]$4f^{13} 6s^2$ 6.1843	70 $^1S_0$ **Yb** Ytterbium 173.04 [Xe]$4f^{14} 6s^2$ 6.2542	71 $^2D_{3/2}$ **Lu** Lutetium 174.967 [Xe]$4f^{14} 5d6s^2$ 5.4259
Actinides	89 $^2D_{3/2}$ **Ac** Actinium (227) [Rn]$6d7s^2$ 5.17	90 $^3F_2$ **Th** Thorium 232.0381 [Rn]$6d^2 7s^2$ 6.3067	91 $^4K_{11/2}$ **Pa** Protactinium 231.03588 [Rn]$5f^2 6d7s$ 5.89	92 $^5L_6$ **U** Uranium 238.02891 [Rn]$5f^3 6d7s^2$ 6.1941	93 $^6L_{11/2}$ **Np** Neptunium (237) [Rn]$5f^4 6d7s^2$ 6.2657	94 $^7F_0$ **Pu** Plutonium (244) [Rn]$5f^6 7s^2$ 6.0260	95 $^8S^\circ_{7/2}$ **Am** Americium (243) [Rn]$5f^7 7s^2$ 5.9738	96 $^9D^\circ_2$ **Cm** Curium (247) [Rn]$5f^7 6d7s^2$ 5.9914	97 $^6H^\circ_{15/2}$ **Bk** Berkelium (247) [Rn]$5f^9 7s^2$ 6.1979	98 $^5I_8$ **Cf** Californium (251) [Rn]$5f^{10} 7s^2$ 6.2817	99 $^4I^\circ_{15/2}$ **Es** Einsteinium (252) [Rn]$5f^{11} 7s^2$ 6.42	100 $^3H_6$ **Fm** Fermium (257) [Rn]$5f^{12} 7s^2$ 6.50	101 $^2F^\circ_{7/2}$ **Md** Mendelevium (258) [Rn]$5f^{13} 7s^2$ 6.58	102 $^1S_0$ **No** Nobelium (259) [Rn]$5f^{14} 7s^2$ 6.65	103 $^2P^\circ_{1/2}$? **Lr** Lawrencium (262) [Rn]$5f^{14} 7s^2 7p$? 4.9 ?

Atomic Number — Ground-state Level
Symbol — 58 $^1G^\circ_4$ **Ce**
Name — Cerium
Atomic Weight† — 140.116
Ground-state Configuration — [Xe]$4f5d6s^2$
Ionization Energy (eV) — 5.5387

†Based upon ^{12}C. () indicates the mass number of the most stable isotope.

For a description of the data, visit physics.nist.gov/data

NIST SP 966 (September 2003)


USA
20c
METRIC 1
2
3
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W-30
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4

Fate of Radioactive Material in the Plant

Form Entering Sewer	Material	Screenings		Rocks/Grit		Biosolids	
		Low	High	Low	High	Low	High
metal pieces	^{60}Co, ^{192}Ir, U, ^{238}Pu, ^{241}Am	*trace*	*?*	*50%*	*100%*	*10%*	*50%*
fine particles	^{60}Co, ^{90}Sr, ^{192}Ir, ^{226}Ra, U, ^{238}Pu, ^{241}Am	*trace*	*?*	*trace*	*10%*	*80%*	*90%*
dissolved	^{60}Co	-	-	-	-	31%	
dissolved or soluble	^{90}Sr, ^{192}Ir, ^{226}Ra, U, ^{238}Pu, ^{241}Am	*trace*	*?*	*trace*	*10%*	*10%*	*50%*
metal, ceramic	^{90}Sr, ^{226}Ra	*trace*	*?*	*50%*	*100%*	*10%*	*50%*
bound to resin	^{99}Mo	*trace*	*?*	*50%*	*90%*	*10%*	*50%*
dissolved	^{131}I	-	-	-	-	2%	
dissolved	^{131}I	-	-	-	-	23%	
dissolved	^{137}Cs	-	-	-	-	12%	

Fate of Radioactive Material in the Plant - 2

Form Entering Sewer	Material	Treated Water		Surfaces	
		Low	High	Low	High
metal pieces	^{60}Co, ^{192}Ir, U, ^{238}Pu, ^{241}Am	*trace*	*trace*	*trace*	*20%*
fine particles	^{60}Co, ^{90}Sr, ^{192}Ir, ^{226}Ra, U, ^{238}Pu, ^{241}Am	*trace*	*10%*	*trace*	*20%*
dissolved	^{60}Co	69%		-	-
dissolved or soluble	^{90}Sr, ^{192}Ir, ^{226}Ra, U, ^{238}Pu, ^{241}Am	*20%*	*80%*	*trace*	*20%*
metal, ceramic	^{90}Sr, ^{226}Ra	*trace*	*trace*	*trace*	*20%*
bound to resin	^{99}Mo	*trace*	*trace*	*trace*	*20%*
dissolved	^{131}I	98%		-	-
dissolved	^{131}I	77%		-	-
dissolved	^{137}Cs	88%		-	-

Potential Exposure Locations

- wastewater in pipes on the way to the plant
- regulator and pumping stations
- wastewater in the treatment plant
- slime and coated surfaces in treatment plant
- screenings in plant
- screenings in dumpster at disposal site
- grit in plant
- grit in dumpster at disposal site
- biosolids in digesters
- biosolids in trucks
- biosolids applied to crops
- crops eaten
- resuspended dust from biosolids
- treated water
- untreated water (bypass)

Issues

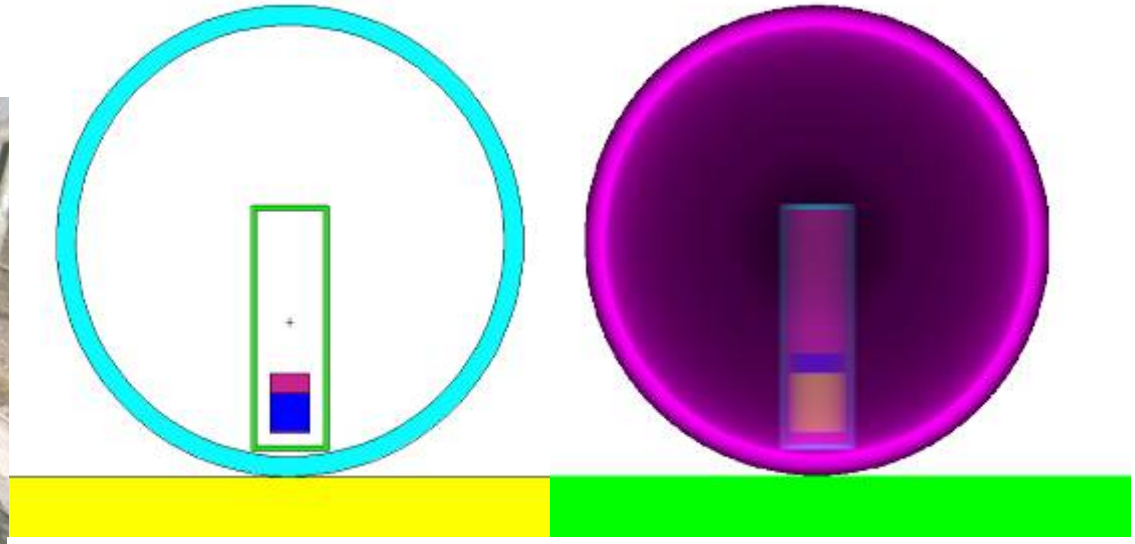
- Disposal of contaminated materials
  - biosolids
  - rags
  - grit
- Current lack of real time monitoring and identification
- Expert consulting agreements
- Research needs
- Regulatory clarity
- Others?

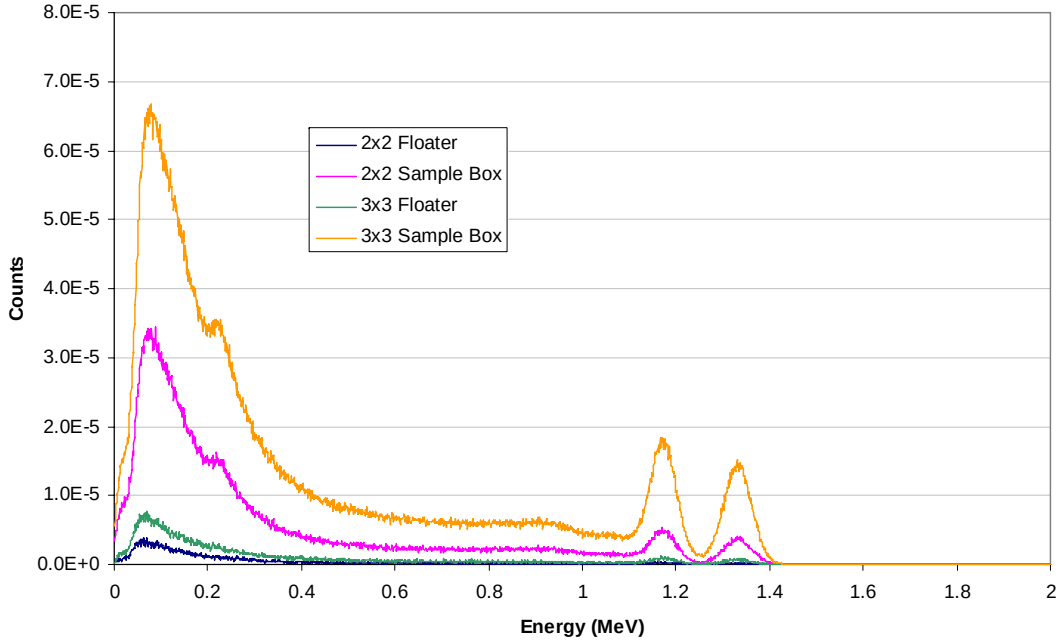
Placement of Sensitive Gamma Radiation Detectors with Central Alarms

- Upstream from the plant in a wet well
- In the raw sewage pump room
- At the screenings conveyor
- At the grit collection point, and
- At the biosolids collection points

- *Instrumentation must be explosion-proof*

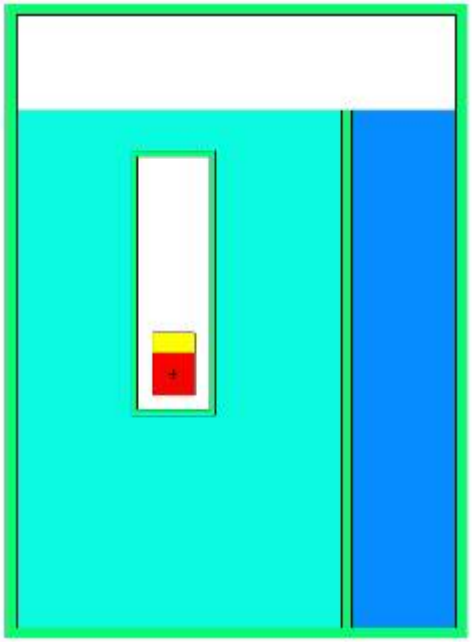
Proposed Floating Monitor for a Wet Well

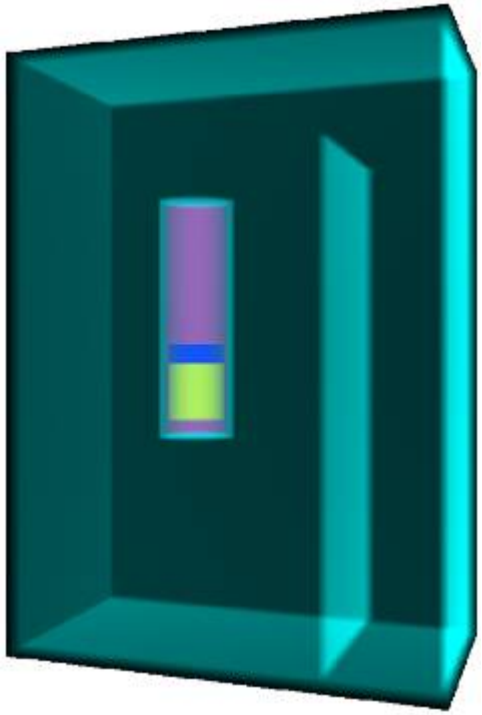




Battelle

Sampling Tank in the Raw Sewage Pump Room





Needs

- Hand-held radioisotope identifiers
- Laboratory analytical equipment
- Real-time monitoring with displays in control room
- Stocks of postings, yellow tape, etc.
- Rapidly-available expert support
  - Emergency response
  - Decontamination

Waste Disposal

- Without prior arrangements, lack of a radioactive waste packaging, transportation, and waste disposal program could obstruct radiation protection of workers and public
- Requires action at the highest political levels

Research Needs - 1

- Practical detection and measurement strategies and technologies using off-the-shelf equipment, and identifying needs and opportunities for innovation
- The transport and fate of radionuclides in wastewater
- The overall benefits, risks, and economic costs to public, workers, environment, and wastewater treatment authorities so that bypass/treat decisions can be made on a sound basis
- Action levels to bypass and resume treatment of wastewater
- Methods of enhancing the removal of radioactive material from wastewater, and sequestration and management of the subsequent radioactive waste

Research Needs - 2

- Methods of, and procedures for, decontaminating wastewater treatment plants in the aftermath of a radiological dispersion event
- Developing a model radiation protection program to keep doses to wastewater treatment workers as low as is reasonably achievable
- Determining the special training needs for wastewater workers involved with a radiological dispersion event
- Methods of minimizing entry of radioactive materials into combined sanitary and storm sewer systems, perhaps by treatment in proximity to the radiological dispersion event

Research Needs - 3

- fixed radiation detection instrumentation to be developed and deployed at a cooperative POTW
  - early warning
  - monitoring at strategic locations within the plant
  - technology demonstration
- planning for rapidly determining where contaminated sewage originated with the goal of limiting further intakes by members of the public, and limiting property damage from contamination

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