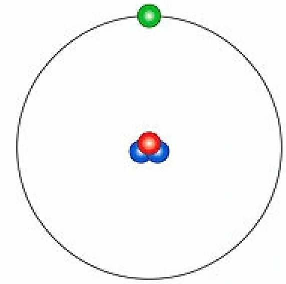
Groundwater Fact Sheet
Radionuclides



Constituent of Concern

Gross Alpha, Gross Beta, Radium, Radon, Uranium, Tritium, Strontium-90, etc.

Synonym

None

Chemical Formula

Gross Alpha	proton-neutron
Gross Beta	electron
Radium	Rd
Radon	Ra
Uranium	U
Tritium	^{3}H
Strontium	Sr-90
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CAS Number

Gross Alpha	12587-46-1
Gross Beta	12587-47-2
Radium 226	13982-63-3
Radium 228	15262-20-1
Radon 222	14859-67-7
Uranium 234	13966-29-5
Uranium 235	15117-96-1
Uranium 238	7440-61-1
Tritium	10028-17-8
Strontium	10098-97-2
..	..

Storet Number

Gross Alpha	01501
Gross Beta	03501
Radium 226+228	11503
Radon 222	82303
Uranium	28012
Tritium	82126
Strontium	13501
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Summary

Radioactive forms of elements are called radionuclides. Radioactive decay is when a radioisotope transforms into another radioisotope; this process emits radiation in some form. Some radionuclides occur naturally in the environment, while others are man-made or produced as byproducts of nuclear reactions. There are many radioactive elements present in the environment. Maximum Contaminant Levels (MCL) have been established by the California State Water Resources Control Board (SWRCB) for uranium, strontium, radium, gross alpha, gross beta particle activity and tritium. The United States Environmental Protection Agency (EPA) has established MCL different from California for uranium, radon, strontium, tritium, and gross beta (adopted by California) particle activity. EPA's MCL for strontium and tritium are covered by gross beta activity.

Some levels of radiation exposure are due to natural background sources (e.g., cosmic radiation, terrestrial, food, etc.). According to the U.S. Nuclear Regulatory Commission the average natural background radiation dose in the United States is approximately 310 mrem/year. Different radioactive constituents will interact and damage biologic activity differently. As a result, some constituents have greater or lower MCL than others. The most common radionuclides in California's groundwater are uranium and gross alpha.

Uranium: Based on SWRCB data from 2007 to 2017, 276 standby and active public supply water wells (4,423 wells tested, 3,643 detections) had at least one detection above the MCL of 20 pCi/L, with a maximum concentration of 1,000 pCi/L. MCL exceedances were most common in San Bernardino (57 wells), Fresno (37 wells), and Madera (30 wells) counties.

Gross alpha: Based on SWRCB data from 2007 to 2017, 561 standby and active public supply water wells (8,779 wells tested, 6,369 detections) had at least one detection of gross alpha radioactivity above the MCL of 15 pCi/L, with a maximum concentration of 920 pCi/L. MCL exceedances were most common in San Bernardino (95 wells), Kern (73), and Fresno (69) counties.

REGULATORY WATER QUALITY LEVELS[1] RADIONUCLIDES			
Constituent	**Type**	**Agency**	**Concentration[2]**
Gross Alpha	MCL	EPA[3] and SWRCB[4]	15 pCi/L
	DLR[5]	SWRCB	3 pCi/L
Gross Beta	MCL (official)	EPA and SWRCB	4 mrem/year (dose)
	MCL[6] (trigger)	EPA	50 pCi/L
	DLR	SWRCB	4 pCi/L
Radium (combined)	MCL	EPA	5 pCi/L
	DLR	SWRCB	1 pCi/L
	PHG[7] (Ra-226)	SWRCB	0.05 pCi/L
	PHG (Ra-228)	SWRCB	0.019 pCi/L
Radon	MCL[8](advisory)	EPA	4,000 pCi/L
	DLR	SWRCB	100 pCi/L
Uranium	MCL	EPA	30 μg/L
	MCL	SWRCB	20 pCi/L
	DLR	SWRCB	1 pCi/L
Tritium	MCL	SWRCB	20,000 pCi/L
	DLR	SWRCB	1,000 pCi/L
Strontium-90	MCL	SWRCB	8 pCi/L
	DLR	SWRCB	2 pCi/L
	PHG	SWRCB	0.35 pCi/L

[1]These levels generally relate to drinking water. Other water and air quality levels may exist. For further information, see *A Compilation of Water Quality Goals*, 17th Edition, (SWRCB, 2016).
[2]Concentrations are reported in milirems (mrem) per year and in picocuries per liter (pCi/L). A 'rem' is a unit of measure describing how a specific type of radiation damages biologic tissue. A milirem is one thousandth of a rem. A curie is a standard unit of radioactivity, where 1 curie is the radioactivity associated with 1 gram of radium. A picocurie is one trillionth of a curie. There is no simple conversion between a curie and a rem.
[3]EPA – United State Environmental Protection Agency
[4]SWRCB - State Water Resources Control Board
[5]DLR = Detection Limit for Purposes of Reporting
[6]This MCL is no longer an official regulatory level, but is still in use as a trigger for EPA and SWRCB-DDW. If the trigger level is exceeded additional testing is required to determine the source of beta radiation and if the MCL has been exceeded.
[7]PHG = Public Health Goal
[8]MCL advisory level; there is no established requirement for radon monitoring. The levels listed here represent proposed levels by the EPA for states that are taking action to reduce radon levels in indoor air by developing an enhanced indoor air program. California currently has an EPA-approved indoor air program.

RADIONUCLIDES DETECTIONS IN PUBLIC WATER WELL SOURCES[9]	
Gross Alpha activities >15 pCi/L	561 of 8,779 wells tested, 6,369 detections
Gross Beta activities >50 pCi/L	zero of 646 wells tested
Radium-226 activities >5 pCi/L Radium-228 activities >5 pCi/L	12 of 2,138 wells tested 7 of 5,379 wells tested
Radon activities >4,000 pCi/L	5 of 132 sources tested
Uranium activities >20 pCi/L	276 of 4,423 tested, 3,643 detections
Tritium activities > 20,000 pCi/L	zero of 164 sources tested
Strontium-90 activities > 8 pCi/L	zero of 143 sources tested

[9]Based on SWRCB data collected from 2007-2017.

ANALYTICAL INFORMATION		
Constituent and Method	**Detection Limit**	**Note**
Gross Alpha: EPA methods 900.0, 00-02 (drinking water), others	1 pCi/L minimum detectable level	Detection limit may vary depending on sample volume, solids concentrations, counting system and time.
Gross Beta: EPA methods 900.0 (drinking water), others	0.5 pCi/L minimum detectable level	
Radium: EPA 903.0, 903.1, others	0.1 pCi/L and up, 1 pCi/L minimum detectable level	
Radon: ASTM D5072, SM-7500 series	1 pCi/L or less	Gas extraction method (D5072) is more accurate but more difficult and requires specialized equipment.
Uranium: EPA 908.0, 908.1, others	1 pCi/L to 0.03 pCi/L, 1 pCi/L minimum detectable level	Roughly 15 methods are approved by the EPA. Type of method selected depends on need.
Tritium: EPA Method 906.0, others	300 pCi/L minimum detectable level	There are eight total EPA approved methods.
Strontium-89 and **Strontium-90**: EPA Method 905.0, others	0.5 pCi/L minimum detectable level	A total of nine methods are approved by the EPA. Some modifications may be required to measure for Sr-89.

[10]The analytical methods here are only a partial list. For a full list of EPA-approved analytical methods please see references number 10 and 11 at the end of the fact sheet.

Radionuclides Occurrence

Radionuclides are naturally occurring elements of the Earth and are present (usually at very low levels) in every substance and material on the planet and may sometimes include several different isotopic versions of the same element. Isotopes are atoms of an element with differing atomic masses (specifically, different numbers of neutrons). Different isotopes will have different radioactive decay properties. As a result, some isotopes may have established health regulatory levels, while others do not. An example is tritium, or 3H. Tritium is an isotope of hydrogen, with three neutrons. The SWRCB-DDW established a regulatory level of 20,000 pCi/L for this isotope. However, the most common isotope of hydrogen is 1H, with one neutron. This isotope of hydrogen is the most abundant element (and isotope) in the universe, is not radioactive, and poses no health risk.

Exposure to naturally occurring radioisotopes is caused by "background radiation". Some background radiation even comes from space. Most radiation detected in groundwater is the result of interactions with natural geologic materials that contain trace levels of radioactive isotopes. Radioactivity is a function of the abundance of radioisotopes and of the decay-rate of that radioisotope.

Gross Alpha

Alpha particles (a-particles) are a type of radiation emitted by radionuclides. They consist of two protons and two neutrons. Their travel range is only a few centimeters. Once alpha particles lose energy, they pick up electrons and become helium. U-238, Ra-226 and Rd-222 are examples of alpha particle emitters. Alpha emitters are used to treat cancer, as a static eliminator in paper mills and other industries, and in smoke detectors.

Gross Beta

Beta particles (β-particles) are a type of radiation emitted by some radionuclides. Beta particles are equivalent to electrons and can travel a few meters in air. After losing their energy, they are picked up by positively charged ions. There are numerous sources of beta particles, including tritium, strontium-90, cesium-137, and products of radium decay. Beta emitters have many uses, especially in medical diagnosis, imaging, and treatment. They can also be used as tracers in agricultural studies (strontium-90), luminous aircraft and commercial exit signs (tritium), drug metabolism studies (tritium), dating organic matter (carbon14), and in a variety of industrial instrumentation.

Radium

Radium is a naturally occurring, silvery white metal formed by decay of uranium and thorium. Multiple isotopes occur at very low levels in virtually all rocks, soil, water, plants and animals. Ra-226 is an alpha emitter and has a half-life of about 1,600 years. Ra-228 is a beta emitter and has a half-life of 5.76 years. Radium decays to form isotopes of radioactive radon and stable lead. Before the risks of radium exposure were understood, mixtures of light emitting radium salts and phosphors were widely used in luminescent paints for clock dials and gauges.

Radon

Radon is a naturally occurring gas and is a product of uranium decay. Radon occurs in groundwater and easily moves into the air. A radon concentration of 10,000 pCi/L in water results in a concentration of 1 pCi/L in the air. Radon is naturally present wherever uranium and radium concentrations in geologic materials are high and tends to be abundant in granitic terrains and certain types of sedimentary deposits. Radon may accumulate in basements and enclosed areas where gases are trapped, and air circulation is low.

Uranium

Uranium is a naturally occurring radioactive element in rocks, soil, water, plants, animals, and humans. There are three main isotopes of uranium (U-234, U-235, and U-238). U-238 is a weakly radioactive metal and contributes to low-level background radiation in the environment. U-238 has a very long half-life of 4.47 billion years. Enriched U-235 is used as fuel in nuclear reactors and in nuclear weapons. Depleted uranium, which is poor in U-235 but rich in U-238, is used by the military in tank armor, bullets, and missiles for its strength and density. Uranium is common in specific types of igneous, metamorphic, and sedimentary rocks.

Recent research indicates that increased concentrations of uranium in groundwater are caused by mobilization of uranium present in soil with irrigation waters containing bicarbonates. Also, nitrate can mobilize uranium through a series of bacterial and chemical reactions.

Tritium

Tritium (^3H) is a naturally occurring isotope of hydrogen (H) that is widely found in all water, although usually at very low concentrations. Tritium is used commercially as an illuminating agent in exit signs and other devices. Tritium is also used in metabolism and new drug studies. While most natural tritium forms as a result of bombardment of the upper atmosphere by cosmic background radiation, significant quantities of tritium are produced in nuclear reactors and in maintenance of thermonuclear devices. Large quantities of Tritium were released into the atmosphere during aboveground nuclear testing in the 1950s and early 1960s. The short half-life (12.32 yrs.) of Tritium is useful in age-dating of young groundwater.

Strontium-90

Strontium-90 is a byproduct of thermonuclear fission between uranium and plutonium. There are several other naturally occurring isotopes of strontium as well. Large quantities of strontium-90 were produced in the 1950s and 1960s by testing of nuclear devices. This strontium was rapidly distributed in the atmosphere throughout the world. The 1986 Chernobyl accident in Ukraine also released large amounts of strontium90 into the atmosphere. Strontium-90 is used as a tracer in agricultural and medical studies, and as a long-term power source for remote buoys, satellites, and other objects.

Remediation and Treatment Technologies

In general, mitigation of drinking water that exceeds a state or federal radionuclide standard is complicated since traditional water treatment processes and disposal methods cannot be routinely implemented. Residuals and wastewater derived from the treatment process for these types of contaminants cannot be easily disposed of. Water systems with sources that exceed drinking water standards for radionuclides may consider implementing the measures summarized below to comply with drinking water quality regulatory requirements.

Mixing Solution: Interconnect with other non-impacted water systems in the area. This option often may be the most cost-effective approach to resolving water quality problems for the long-term. Depending on the water quality and yield of each source, water from different sources may be blended to meet drinking water standards, or new sources may be developed.

Geologic solution: determine if certain water bearing zones can be isolated to improve water quality and comply with radionuclide regulatory requirements.

Gross Alpha

The presence of alpha particles in water usually indicates radium-226, U-235 and Rd-222 as the source. As shown in the attached maps (Figs. 1, 2) distribution of uranium and gross alpha activities above MCL levels is closely related. Water should be tested for a source of radioactivity and treated appropriately.

Gross Beta

The presence of beta particles in water usually indicates radium-226 and tritium as the source. Water should be tested for a source of radioactivity and treated appropriately.

Radium

The most inexpensive treatment method is synthetic zeolite ion exchange like home water softeners, which removes roughly 90% of the radium. Other possible treatment methods include lime-soda ash softening and reverse osmosis. Comparatively high start-up and operating costs may make these options impractical for most affected systems. Technologies being tested include an adsorptive media where water is passed through columns for treatment, and oxidationcoagulation flocculation-filtration method.

Radon

Granular activated carbon filters (GAC) use activated carbon to remove the radon. Aeration devices, which bubble air through the water and carry radon gas out into the atmosphere through an exhaust fan, are another alternative.

Uranium

Processes include reverse osmosis, anion exchange, special adsorbent media, distillation, or lime softening.

Tritium

Mixing or geologic solutions are most effective.

Strontium-90

Reverse osmosis and activated charcoal is effective. Mixing and geologic solutions may also be appropriate.

Health Effect Information

Gross Alpha

The health effect of alpha particles depends upon how exposure takes place. External exposure is far less of a concern than internal exposure because alpha particles lack the energy to penetrate the outer dead layer of skin. If alpha emitters have been inhaled, ingested, or absorbed into the blood stream, living tissue may be exposed. Exposure of living tissue to alpha radiation is associated with an increased risk of cancer, in particular lung cancer (inhalation). The greatest exposure to alpha radiation comes from the inhalation of radon and its decay products, several of which also emit potent alpha radiation.

Gross Beta

Beta radiation can cause both acute and chronic health effects. Contact with a strong beta source from an abandoned industrial instrument may result in acute exposure. Chronic effect results from low-level exposure over a long period (approximately 5-30 years). The main chronic health effect from radiation is cancer. When taken internally beta emitters can cause tissue damage, which increases the risk of developing cancer. Some beta emitters, such as carbon-14, distribute widely throughout the body. Others accumulate in specific organs; iodine-131 in the thyroid gland, strontium-90 in bone and teeth.

Radium

Radium is known to cause bone cancer when consumed in high doses. The National Academy of Sciences (NAS) has concluded that a long-term exposure to elevated levels of radium in drinking water poses a higher risk of bone cancer for those exposed. In the 1920s, radium paint was used to make watch dials luminescent. The workers who painted the watch dials would touch the paintbrush tips to their tongues, and inadvertently swallowed high doses of radium. In the decades since, this group of occupationally exposed workers (approximately 4,000) has developed an extremely high rate of death from bone cancer. This effect of radium has also been documented in laboratory animals.

Radon

Breathing radon in indoor air can cause lung cancer. Radon inhalation is the second leading cause of lung cancer, behind smoking, and causes approximately 21,000 deaths a year in the U.S. Most radon that enters indoor spaces comes from degassing of natural geologic deposits. Only about 1-2 percent of radon in the air comes from drinking water. Drinking water that contains radon also presents a risk of developing internal organ cancers, primarily stomach cancer. Based on a NAS report, the EPA estimates than radon in drinking water causes about 168 cancer deaths per year: 89% from lung cancer caused by breathing radon released to indoor air from water and 11% from stomach cancer caused by consuming water containing radon.

Uranium

Exposure to uranium can result in both chemical and radiological toxicity. Natural uranium consists primarily of the U-238, which is very weakly radioactive, and it is not a hazardous radioactive substance. However, uranium is a weak chemical poison that can seriously damage the kidneys at high blood concentrations. This damage is dosage dependent and somewhat reversible. The uranium ion (uranyl) can also deposit on bone surfaces and may be detected in the bone matrix for several years following exposure.

Tritium

Tritium is a beta-emitter, and like all beta emitters it contributes to an increased risk of cancer. However, tritium rapidly exits the body and overall is one of the least-dangerous radionuclides. Tritium is naturally found in very low levels in all water.

Strontium-90

Strontium is similar chemically to calcium, and tends to accumulate in bones, where calcium is normally deposited. Increased exposure to strontium-90 has been linked to bone cancer, cancer near bones, and leukemia.

Key Resources

1. Argonne National Laboratory-Environmental Science Division (EVS)-Radiological and Chemical Fact Sheets to support Health Risk Analyses for Contaminated Areas https://remm.hhs.gov/ANL_ContaminantFactSheets_All_070418.pdf
2. California Safe Drinking Water Act & Related Laws and Regulations- Article 5. 2017. Radioactivity from Title 22 California Code of Regulation. https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/lawbook/dwregulations-2017-04-10.pdf
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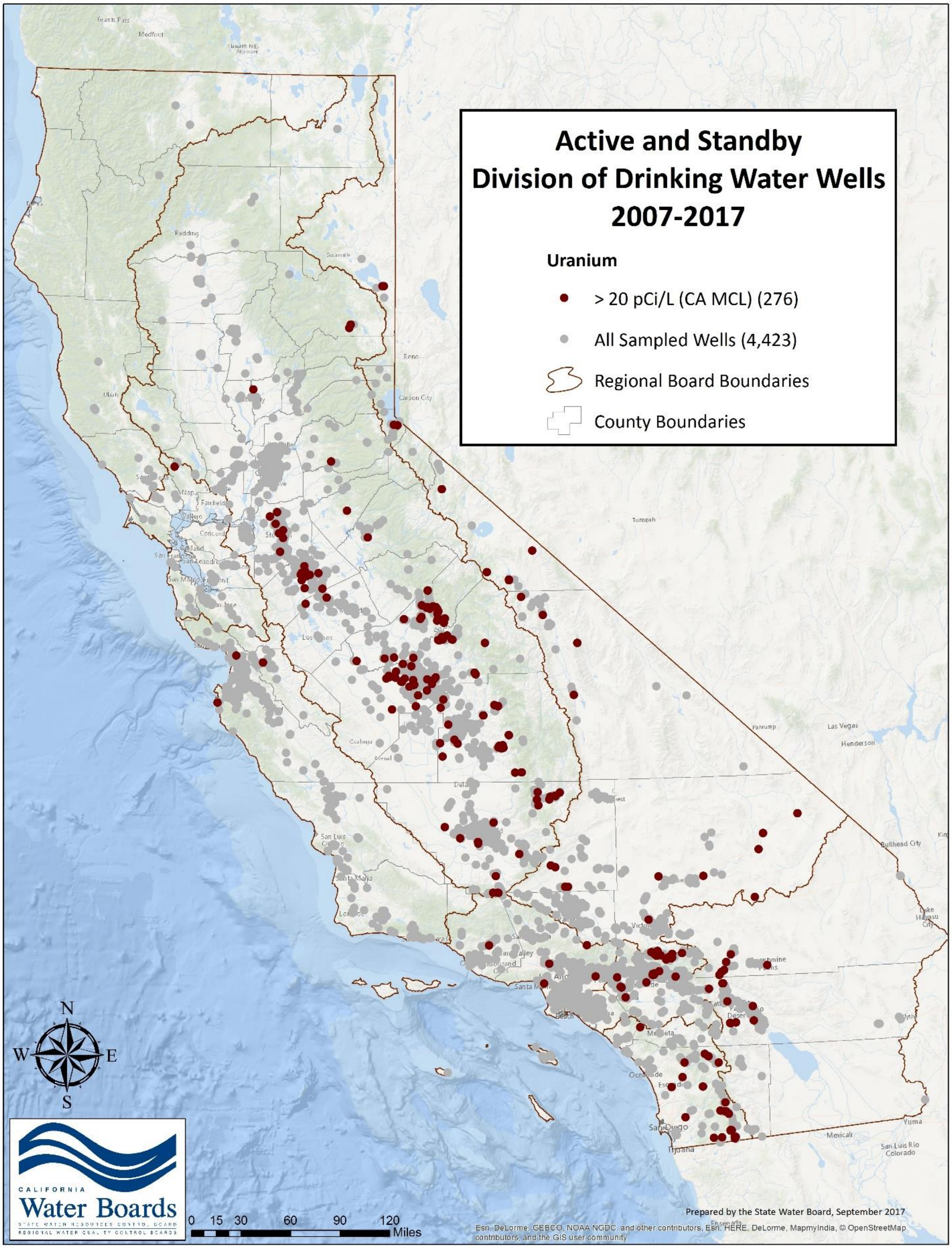

Figure 1. Active and standby public drinking water wells that had at least one detection of uranium above the MCL, 2007-2017, 276 wells. Source: GAMA GIS.

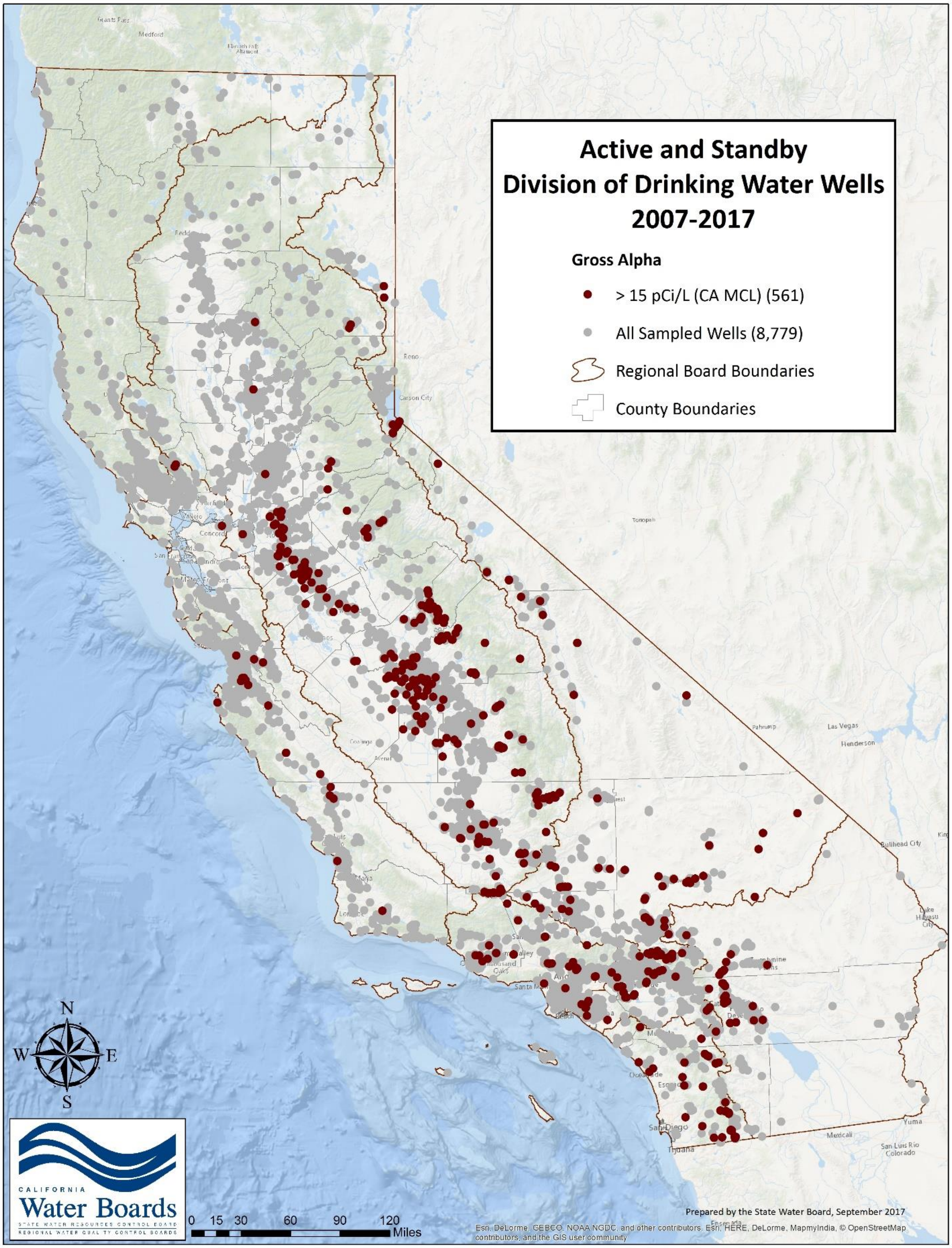

Figure 2. Active and standby public drinking water wells that had at least one detection of gross alpha activity above the MCL, 2007-2017, 561 wells. Source: GAMA GIS.