Health-Protective Considerations Regarding Measurement of Gross Beta Particle and Photon Activity in Drinking Water

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SUMMARY

The Office of Environmental Health Hazard Assessment (OEHHA) has examined the practicality of proposing a gross beta particle/photon Public Health Goal (PHG). Health and Safety Code Section 116365(c)(1) directs OEHHA to "prepare and publish an assessment of the risks to public health posed by each contaminant for which the department proposes a primary drinking water standard." The risk assessment must contain "an estimate of the level of the contaminant in drinking water that is not anticipated to cause or contribute to adverse health effects, or that does not pose any significant risk to health. This level shall be known as the public health goal for the contaminant."

OEHHA has concluded that it would not be practical to develop a PHG for the category of beta particle and photon emitters, despite the fact that this category has a primary standard, or maximum contaminant level (MCL), which is 50 pCi/L by state law and 4 mrem by federal law. There are several reasons why development of a PHG for gross beta/photon activity is not practical. The most important reason is that the designation of gross beta/photon activity does not refer to a specific chemical contaminant, but rather to a group of radioactive elements. Furthermore, the MCL represents only a screening level for assay of radioactivity produced by the group of radionuclides. If excessive activity levels are found, further sample characterization is required, and selected isotopes are subject to regulation under specific MCLs. OEHHA is developing PHGs for the isotopes for which there are MCLs.

The use and choice of a screening level is in this case a risk management decision, based on consideration of cost and feasibility, and therefore to develop a PHG, based exclusively on health-based considerations, for the gross beta measure appears to be inappropriate. OEHHA believes it is useful, however, to describe the estimated risks associated with various levels of beta/photon emission, which could serve a useful role in the selection of a screening level.

Another consideration is that not all beta/photon particle emitters were covered under the screening method. The gross beta particle/photon MCL was originally intended by U.S. EPA to screen drinking water for an unacceptable amount of radioactivity from man-made sources, with the exception of the man-made isotopes strontium-90 and tritium. Some of the natural beta emitters are also excluded from this screening. Other beta/photon emitters are considered under the similar screening standard for gross alpha particle activity. It may be more appropriate to evaluate all natural beta/photon emitters

under the gross alpha particle screening procedure, since the conditions of that screen specify evaluating both surface and ground water sources.

Although other health impacts are possible, cancer has been recognized as the major health effect of most studied radionuclides. Moreover, risk assessment procedures to estimate the cancer risk from radionuclides have been well developed. Thus cancer is the principal endpoint that will be used to evaluate the health risk from beta particle/photon emitters. Cancer risk estimates for exposure to beta/photon radioactivity vary with particle energy and how certain organs handle that energy. Therefore, risk-based health protective values vary for the different beta/photon emitting isotopes.

Based on current U.S. EPA risk coefficients, a significant proportion of the potential beta photon emitters in drinking water could pose a higher than *de minimis* 10^{-6} cancer risk if present at radioactivity levels of 50 pCi/L (1.85 Bq/L) or less. This document discusses relative cancer risk and exposure possibilities for various beta/photon emitters, with the intention of providing a perspective on the risks associated with the screening levels for this radiation category. It does not propose a specific screening level for gross beta/photon emission, because this involves analytical considerations, which are not considered in the development of exclusively health-based values. As the appropriate health-protective value varies for different chemicals, no single "screening level" would be appropriate for all the radionuclides of this class. However, with better characterization, risks of the beta particle/photon emitters in water can be estimated using the U.S. EPA cancer coefficients specific for each radionuclide.

INTRODUCTION

Elements that contain unstable nuclei are said to be radioactive or are called radionuclides. This instability is manifested as the potential to decay or fall into a lower energy state by releasing principally either alpha or beta particles, or gamma rays. An alpha particle is defined as a positively charged particle consisting of two protons and two neutrons. A beta particle is either a negatively charged negatron/electron or a positively charged particle (positron). Gamma rays are high energy, short-wavelength electromagnetic radiation. Radioactive emissions are measured by an activity unit called a Curie (Ci), representing 3.7×10^{10} disintegrations per second. For drinking water, the common representation of activity is the picoCurie (pCi), equal to 10^{-12} Ci. Another representation of radioactivity is the Becquerel (Bq), which is one disintegration per second (1 pCi = 3.7^{-2} Bq).

Energetic atoms of radionuclides release their energy either through particles or electromagnetic radiation, which may in turn interact with other atoms or matter, particularly to knock electrons out of their orbits around the nucleus. This process is defined as ionizing radiation. Ionizing radiation is a particular concern for living tissues as it could lead to changes in important constituents of the cell, including DNA, and result in changes in structure and function of the cells or organ systems. Understanding the potential for ionizing radiation to effect changes to cells and tissues requires knowing how much energy is deposited in the tissues as a result of these emissions. This concept is referred to as the absorbed dose and is represented by units of rad (radiation absorbed dose), which is the amount of energy (in units of 100 ergs) deposited in one gram of

matter or tissue. In International Units, the Gray (Gy) is used for characterizing absorbed dose, representing one joule/kg of energy deposited, and is equivalent to 100 rad.

However, the radiation particles or energy types differ in their ability to affect tissues, and thus an adjustment or quality factor can be used to account for the differences. For example, an alpha particle deposits its energy in a short range and rarely can penetrate the surface layers of tissues, while beta particle and gamma radiation deposit their energies over a greater range. The rem (roentgen exposed man) unit accounts for the difference in the type of radiation by multiplying the absorbed dose in rads by a quality factor; this can also be represented as sieverts (Sv), equaling 100 rem. Another fine-tuning of the absorbed dose is to adjust for the different types of organs affected by radioactive emissions; this is referred to as rem-ede (effective dose-equivalent).

CURRENT CALIFORNIA REGULATIONS AND GUIDANCE

The primary drinking water standards for the State of California include Maximum Contaminant Levels (MCLs) for natural and man-made radioactivity (California Code of Regulations - Title 22, Division 4, Chapter 15, Article 5). Section 64443 of the California code addresses Man-Made Radioactivity and states the following:

> Water systems with greater than 30,000 service connections and using surface water sources shall monitor their water supplies for tritium, strontium-90 and gross beta particle activity at least once every four years.
>
> (a) The average concentration of beta particle activity and photon radioactivity from man-made radionuclides in drinking water shall not produce an annual dose equivalent to the total body or any internal organ greater than four millirem/year.
>
> (b) Compliance with this requirement is assumed if the average concentration of gross beta particle activity is less than 50 pCi/L and if the average concentrations of tritium and strontium-90 are less than those listed on Table 4.
>
> (c) If the gross beta particle activity exceeds 50 pCi/L, an analysis of the sample shall be performed to identify the major radioactive constituent present and the appropriate organ and total body doses shall be calculated.
>
> (d) The water supplier shall report information on sample results that exceed the maximum contaminant levels to the Department within 48 hours.

This section on man-made radioactivity requires surface water systems of a certain size to comply with a standard of 4 mrem/yr annual dose equivalent to the total body or any internal organ for beta particle and photon radioactivity. Water systems can show compliance when the average concentration of gross beta activity is less than the MCL of 50 pCi/L, providing that the tritium and strontium-90 MCLs are met.

Table 4 in Section 64443 of the California code lists the MCL for gross beta particle activity as 50 pCi/L. While the strontium-90 and tritium MCLs are specific to individual beta-emitting constituents, the gross beta particle/photon MCL is not. The gross beta measurement is a relatively easy and quick laboratory technique originally developed to screen water samples for the presence of beta-emitting radionuclides. If systems meet

this standard, they do not need to analyze for individual beta and photon emitting radionuclides other than tritium and strontium-90.

REGULATORY BACKGROUND

It should be noted that the California standard specifies that the MCL for gross beta/photon particle activity is 50 pCi/L. Compliance with the federal 4 mrem/yr requirement is assumed, providing that the average water concentrations are below the 50 pCi/L gross beta MCL (15 pCi for vulnerable systems, i.e., those considered to be near known sources). The U.S. EPA specifies that the MCL is the 4 mrem/yr value, with the 50 pCi/L as a screening tool but not a specific MCL.

In setting the 1976 MCL for man-made beta particle and photon radioactivity at 4 mrem/yr, the U.S. EPA stated that the limit was chosen primarily on the basis of avoiding undesirable future contamination of public water supplies as a result of controllable human activities. The U.S. EPA performed a health risk assessment using the cancer risk estimates from the BEIR I report (NAS, 1972) and calculated that an exposure of 4 mrem/year corresponded to a lifetime cancer risk increase of about 0.8×10^{-6} per year. The U.S. EPA did not anticipate that the MCL would be exceeded except in extraordinary circumstances. The levels of fallout radioactivity in public water supplies were declining, and controls on releases of materials from the nuclear industry were in place.

In 1991, the U.S. EPA proposed to retain the 4 mrem/year MCL. However, they modified the standard based on the concept of committed effective dose equivalent (EDE). An EDE approach adjusts the allowable dose an individual organ may receive based on its radiosensitivity.

In their final 2000 rule, the U.S. EPA retained the original 1976 standard. When the risks were calculated using the most recent dosimetry models described in Federal Guidance Report No. 13, the cancer risks associated with the MCL generally fall within the Agency's current risk target range of 10^{-6} to 10^{-4}. The U.S. EPA has stated that it intends to reevaluate this MCL in the near future (U.S. EPA, 2000).

OCCURRENCE OF GROSS BETA AND BETA-PHOTON ACTIVITY IN DRINKING WATER

The State of California measured over 19,600 public drinking water supply wells from 1984 to 2000 for various radioactive contaminants, with a subset analyzed for gross beta particle activity. Gross beta activity was reported in 1,289 out of 2,360 assays (DHS, 2002), although there were no instances in which the MCL of 50 pCi/L was exceeded. Based on these data, a low level of gross beta activity is relatively prevalent in the State's water supply, probably due to the ubiquitous nature of naturally occurring beta particle-emitting radionuclides.

The U.S. EPA's Environmental Radiation Ambient Monitoring System (ERAMS) collects and publishes quarterly data on gross beta and the beta-emitters tritium, strontium-90, and iodine-131 in selected surface water and groundwater throughout the nation. They also measure and report on specific gamma activity from composite

drinking water samples. Gross beta activity ranged from 0.3 to 17.8 pCi/L (0.01-0.66 Bq/L), with an average value of 3 pCi/L (0.11 Bq/L) over a three-year period, well below the 50 pCi/L gross beta-particle activity screening level that would require testing for individual isotopes (U.S. EPA, 2000). There was no instance in the ERAMS database in which gross beta-particle concentrations in surface water exceeded the 50 pCi level. Anthropogenic sources of beta/photon-emitting radionuclide contamination can include Department of Energy Facilities, commercial nuclear power plants, research facilities, hospitals, universities and pharmaceutical companies. Atmospheric fallout is not currently a major source of contamination due to the declining levels of bomb-generated beta/photon-emitting radionuclides since the moratorium on atmospheric testing. In the last full year of reported results (1998), ERAMS detected iodine-131 in only 12 out of 96 drinking water samples (U.S. EPA, 2000). The concentrations were very low, ranging from 0.08 to 0.53 pCi/L (<0.02 Bq/L). All twelve detections were not more than two times the minimum detectable concentration (MDC).

The ERAMS program also measures specific gamma-emitting radionuclides in the drinking water samples. All detected radionuclides were naturally occurring and included potassium-40, thallium-208, bismuth-212, -214, and lead-212 and -214. Potassium-40 was detected most frequently and at the highest concentrations (5–93 pCi/L, 0.19-3.44 Bq/L).

Nationwide gross beta-particle activity for groundwater was determined from the National Inorganics and Radionuclides Survey (Longtin, 1988). Of the 900 public water supplies sampled, nine had gross beta activities above 50 pCi/L. The radionuclides responsible for the high gross beta values were unknown, but an analysis of the data indicates it is not Ra-228, a common beta particle emitter.

Lead-210, a naturally occurring beta particle emitter, exceeds the MCL of 4 mrem/yr at the 50 pCi/L gross beta activity screening level. A U.S. EPA study of central Florida ground waters found concentrations of lead-210 from 0 to 0.6 pCi/L in 25 municipal water supplies (U.S. EPA, 2000). In a recent United States Geological Survey study (USGS, 1998), lead-210 was assayed for in 96 raw water samples from 27 states. The maximum concentration was 4.1 pCi/L (0.15 Bq/L) in a sample collected from the geological region known as the Appalachian Province in Connecticut. Approximately 10 percent of the samples exceeded a lead-210 concentration of 1 pCi/L (the MDC), but only one exceeded 3 pCi/L (0.11 Bq/L). The greatest frequency of detection was centered in the northeast U.S.

As a continuation of the National Inorganics and Radionuclides Survey, the U.S. EPA performed an additional data collection effort that was completed in 1999 (U.S. EPA, 2000). They analyzed 26 public water systems for common manmade and naturally occurring beta and photon emitting radionuclides including the manmade nuclides tritium, strontium-90 and -89, cesium-134 and -137, iodine-131, and cobalt-60, and the naturally occurring radionuclides, potassium-40, uranium-234, -235, and -238, radium-226 and -228, and lead-210. No samples contained detectable concentrations of any manmade radionuclides. Naturally occurring potassium-40 was a significant source of beta particle activity in the majority of the 26 samples analyzed. The concentration of potassium-40 exceeded 3 pCi/L in nine of the 26 samples. Radium-228 was also found to

be a significant source of beta particle activity, with a maximum concentration of 3.1 pCi/L (0.11 Bq/L). Lead-210 was detected below 1 pCi/L (0.037 Bq/L) in all samples.

CANCER RISKS FROM BETA AND PHOTON-EMITTING RADIONUCLIDES IN DRINKING WATER

The beta/photon particle radionuclide class has many members. The risks from some significant beta/photon emitters, radium-228, strontium-90, and tritium will not be addressed in this section, because radium-228 is addressed under the gross alpha monitoring scheme, while strontium-90 and tritium are assessed under individual PHGs (to be developed) and have their own MCLs. The approximately 200 other beta/photon emitters have cancer morbidity risk coefficients developed by U.S. EPA, which can be found in Federal Guidance Report No. 13 (U.S. EPA, 1999). Table 1 below lists the cancer risk coefficients for the water ingestion exposure route for most environmentally significant radionuclides. In addition, the table lists the unit lifetime risk concentrations for drinking water (in risk per pCi/L) assuming a drinking water consumption rate of two liters per day for a 70-year lifetime, and the concentration that yields a 10^{-6} lifetime cancer risk from drinking water.

Table 1. Federal Guidance Report No. 13 Cancer Risk Coefficients, Unit Risk Quantities for Drinking Water Concentrations, and the Concentrations Yielding a 1 in a Million Lifetime Cancer Risk for Environmentally Significant Radionuclides

Radionuclide	Morbidity Risk Coefficients (per Bq)	Risk per pCi/L in drinking water	Conc. at 10^{-6} Risk (pCi/L)
^{3}H	1.37×10^{-12}	2.59×10^{-9}	3.86×10^{2}
^{14}C	4.20×10^{-11}	7.94×10^{-8}	$1.26 \times 10^{+1}$
^{22}Na	2.60×10^{-10}	4.92×10^{-7}	2.03
^{32}P	2.42×10^{-10}	4.58×10^{-7}	2.19
^{33}P	2.65×10^{-11}	5.01×10^{-8}	$2.00 \times 10^{+1}$
^{35}S	1.39×10^{-11}	2.63×10^{-8}	$3.81 \times 10^{+1}$
^{36}Cl	8.92×10^{-11}	1.69×10^{-7}	5.93
^{40}K	6.68×10^{-10}	1.26×10^{-6}	$7.92 \times 10^{+1}$
^{45}Ca	6.68×10^{-11}	1.26×10^{-7}	7.92
^{46}Sc	1.68×10^{-10}	3.18×10^{-7}	3.15
^{44}Ti	6.93×10^{-10}	1.31×10^{-6}	$7.63 \times 10^{+1}$
^{48}V	2.22×10^{-10}	4.20×10^{-7}	2.38
^{51}Cr	5.01×10^{-12}	9.47×10^{-9}	$1.06 \times 10^{+2}$
^{54}Fe	6.16×10^{-11}	1.16×10^{-7}	8.59
^{55}Fe	2.33×10^{-11}	4.41×10^{-8}	$2.27 \times 10^{+1}$
^{59}Fe	2.13×10^{-10}	4.03×10^{-7}	2.48
^{58}Co	7.97×10^{-11}	1.51×10^{-7}	6.64

Radionuclide	Morbidity Risk Coefficients (per Bq)	Risk per pCi/L in drinking water	Conc. at 10^{-6} Risk (pCi/L)
^{60}Co	4.25×10^{-10}	8.04×10^{-7}	1.24
^{63}Ni	1.81×10^{-11}	3.42×10^{-8}	$2.92 \times 10^{+1}$
^{65}Zn	3.15×10^{-10}	5.96×10^{-7}	1.68
^{68}Ge	7.64×10^{-10}	1.44×10^{-8}	$6.92 \times 10^{+1}$
^{75}Se	2.20×10^{-10}	4.16×10^{-7}	2.40
^{86}Rb	2.67×10^{-10}	5.05×10^{-7}	1.98
^{89}Sr	3.47×10^{-10}	6.56×10^{-7}	1.52
^{90}Sr	1.51×10^{-9}	2.85×10^{-6}	$3.50 \times 10^{+1}$
^{90}Y	4.88×10^{-10}	9.23×10^{-7}	1.08
^{91}Y	4.33×10^{-10}	8.19×10^{-7}	1.22
^{93}Zr	2.01×10^{-11}	3.80×10^{-8}	$2.63 \times 10^{+1}$
^{95}Zr	1.24×10^{-10}	2.34×10^{-7}	4.27
^{94}Nb	2.10×10^{-10}	3.97×10^{-7}	2.52
^{95}Nb	6.63×10^{-11}	1.25×10^{-7}	7.98
^{99}Mo	4.33×10^{-11}	8.19×10^{-8}	$1.22 \times 10^{+1}$
^{99}Tc	7.44×10^{-11}	1.41×10^{-7}	7.11
^{103}Ru	1.04×10^{-10}	1.97×10^{-7}	5.09
^{106}Ru/Rh	1.14×10^{-9}	2.16×10^{-6}	$4.64 \times 10^{+1}$
^{110}Ag m	2.67×10^{-10}	5.05×10^{-7}	1.98
^{109}Cd	1.35×10^{-10}	2.55×10^{-7}	3.92
^{113}Cd m	7.77×10^{-10}	1.47×10^{-6}	$6.81 \times 10^{+1}$
^{114}In m	6.70×10^{-10}	1.27×10^{-6}	$7.89 \times 10^{+1}$
^{113}Sn	1.17×10^{-10}	2.21×10^{-7}	4.52
^{123}Sn	3.78×10^{-10}	7.15×10^{-7}	1.40
^{125}Sn	5.43×10^{-10}	1.03×10^{-6}	$9.74 \times 10^{+1}$
^{126}Sn	6.91×10^{-10}	1.31×10^{-6}	$7.65 \times 10^{+1}$
^{124}Sb	3.48×10^{-10}	6.58×10^{-7}	1.52
^{126}Sb	3.00×10^{-10}	5.67×10^{-7}	1.76
^{127}Sb	2.72×10^{-10}	5.14×10^{-7}	1.94
^{127}Te	2.71×10^{-11}	5.12×10^{-8}	$1.95 \times 10^{+1}$
^{129}Te	4.62×10^{-12}	8.74×10^{-9}	$1.14 \times 10^{+2}$
^{109}Te m	4.14×10^{-10}	7.83×10^{-7}	1.28
^{131}Te m	2.23×10^{-10}	4.22×10^{-7}	2.37
^{125}I	6.87×10^{-10}	1.30×10^{-6}	$7.70 \times 10^{+1}$
^{129}I	3.99×10^{-9}	7.54×10^{-6}	$1.33 \times 10^{+1}$
^{131}I	1.23×10^{-9}	2.33×10^{-6}	$4.30 \times 10^{+1}$
^{134}Cs	1.14×10^{-9}	2.16×10^{-6}	$4.64 \times 10^{+1}$
^{136}Cs	2.34×10^{-10}	4.42×10^{-7}	2.26

Radionuclide	Morbidity Risk Coefficients (per Bq)	Risk per pCi/L in drinking water	Conc. at 10^{-6} Risk (pCi/L)
^{137}Cs/Ba	8.22×10^{-10}	1.55×10^{-6}	$6.43 \times 10^{+1}$
^{133}Ba	1.84×10^{-10}	3.48×10^{-7}	2.87
^{140}Ba	4.03×10^{-10}	7.62×10^{-7}	1.31
^{140}La	2.96×10^{-10}	5.60×10^{-7}	1.79
^{141}Ce	1.25×10^{-10}	2.36×10^{-7}	4.23
^{143}Ce	1.92×10^{-10}	3.63×10^{-7}	2.75
^{144}Ce/Pr	9.54×10^{-10}	1.80×10^{-6}	$5.54 \times 10^{+1}$
^{147}Nd	1.88×10^{-10}	3.55×10^{-7}	2.81
^{145}Pm	1.51×10^{-11}	2.85×10^{-8}	$3.50 \times 100^{+1}$
^{147}Pm	4.57×10^{-11}	8.64×10^{-8}	$1.16 \times 100^{+1}$
^{149}Pm	1.80×10^{-10}	3.40×10^{-7}	2.94
^{151}Pm	1.22×10^{-10}	2.31×10^{-7}	4.34
^{151}Sm	1.50×10^{-11}	2.84×10^{-8}	$3.53 \times 10^{+1}$
^{152}Eu	1.64×10^{-10}	3.10×10^{-7}	3.23
^{154}Eu	2.79×10^{-10}	5.28×10^{-7}	1.90
^{155}Eu	5.13×10^{-11}	9.70×10^{-8}	$1.03 \times 10^{+1}$
^{153}Gd	4.12×10^{-11}	7.79×10^{-8}	$1.28 \times 10^{+1}$
^{160}Tb	2.35×10^{-10}	4.44×10^{-7}	2.25
^{166}Ho m	2.17×10^{-10}	4.10×10^{-7}	2.44
^{170}Tm	2.41×10^{-10}	4.56×10^{-7}	2.19
^{169}Yb	1.08×10^{-10}	2.04×10^{-7}	4.90
^{181}Hf	1.72×10^{-10}	3.25×10^{-7}	3.08
^{182}Ta	2.15×10^{-10}	4.07×10^{-7}	2.46
^{187}W	9.92×10^{-11}	1.88×10^{-7}	5.33
^{192}Ir	1.99×10^{-10}	3.76×10^{-7}	2.66
^{198}Au	1.70×10^{-10}	3.21×10^{-7}	3.11
^{203}Hg	1.54×10^{-10}	2.91×10^{-7}	3.43
^{204}Tl	1.58×10^{-10}	2.99×10^{-7}	3.35
^{210}Pb	2.38×10^{-8}	4.50×10^{-5}	$2.22 \times 10^{+2}$
^{207}Bi	1.53×10^{-10}	2.89×10^{-7}	3.46
^{210}Bi	2.41×10^{-10}	4.56×10^{-7}	2.19
^{210}Po	4.97×10^{-8}	9.40×10^{-5}	$1.06 \times 10^{+2}$
^{228}Ra	1.04×10^{-8}	1.97×10^{-5}	$5.09 \times 10^{+2}$
^{227}Ac	5.43×10^{-9}	1.03×10^{-5}	$9.74 \times 10^{+2}$
^{227}Th	1.28×10^{-9}	2.42×10^{-6}	$4.13 \times 10^{+1}$
^{228}Th	2.90×10^{-9}	5.48×10^{-6}	$1.82 \times 10^{+1}$
^{230}Th	2.46×10^{-9}	4.65×10^{-6}	$2.15 \times 10^{+1}$
^{232}Th	2.73×10^{-9}	5.16×10^{-6}	$1.94 \times 10^{+1}$

Radionuclide	Morbidity Risk Coefficients (per Bq)	Risk per pCi/L in drinking water	Conc. at 10^{-6} Risk (pCi/L)
^{231}Pa	4.67×10^{-9}	8.83×10^{-6}	$1.13 \times 10^{+1}$
^{232}U	7.88×10^{-9}	1.49×10^{-5}	$6.71 \times 10^{+2}$
^{233}U	1.94×10^{-9}	3.67×10^{-6}	$2.73 \times 10^{+1}$
^{234}U	1.91×10^{-9}	3.61×10^{-6}	$2.77 \times 10^{+1}$
^{235}U	1.88×10^{-9}	3.55×10^{-6}	$2.81 \times 10^{+1}$
^{238}U	1.73×10^{-9}	3.27×10^{-6}	$3.06 \times 10^{+1}$
^{237}Np	1.67×10^{-9}	3.16×10^{-6}	$3.17 \times 10^{+1}$
^{239}Np	1.39×10^{-10}	2.63×10^{-7}	3.81
^{236}Pu	2.02×10^{-9}	3.82×10^{-6}	$2.62 \times 10^{+1}$
^{238}Pu	3.55×10^{-9}	6.71×10^{-6}	$1.49 \times 10^{+1}$
^{239}Pu	3.64×10^{-9}	6.88×10^{-6}	$1.45 \times 10^{+1}$
^{240}Pu	3.65×10^{-9}	6.90×10^{-6}	$1.45 \times 10^{+1}$
^{241}Pu	4.77×10^{-11}	9.02×10^{-8}	$1.11 \times 10^{+1}$
^{242}Pu	3.46×10^{-9}	6.54×10^{-6}	$1.53 \times 10^{+1}$
^{241}Am	2.81×10^{-9}	5.31×10^{-6}	$1.88 \times 10^{+1}$
^{242}Am m	1.91×10^{-9}	3.61×10^{-6}	$2.77 \times 10^{+1}$
^{243}Am	2.79×10^{-9}	5.28×10^{-6}	$1.90 \times 10^{+1}$
^{242}Cm	1.04×10^{-9}	1.97×10^{-6}	$5.09 \times 10^{+1}$
^{243}Cm	2.56×10^{-9}	4.84×10^{-6}	$2.07 \times 10^{+1}$
^{244}Cm	2.26×10^{-9}	4.27×10^{-6}	$2.34 \times 10^{+1}$
^{245}Cm	2.82×10^{-9}	5.33×10^{-6}	$1.88 \times 10^{+1}$
^{246}Cm	2.76×10^{-9}	5.22×10^{-6}	$1.92 \times 10^{+1}$

Cancer Risk from Measured Values

Using the maximum measured values from the National Inorganics and Radionuclides Survey (Longtin, 1988) indicated in the previous section, we calculated the maximum risks for potassium-40, iodine-131 and lead-210 for an assumed lifetime of exposure. These radionuclides represent some of the most carcinogenic and likely occurring emitters in water. The cancer risks are listed in Table 2 below. The maximum estimated lifetime risk values range from 10^{-6} to 10^{-4}.

Table 2. Lifetime Cancer Risk from Maximum Measured Concentrations in Drinking Water for K-40, I-131 and Pb-210

Radionuclide	Maximum Concentration (pCi/L)	Risk (per pCi/L in drinking water)	Maximum Lifetime Cancer Risk
^{131}I	0.53	2.33×10^{-6}	1.2×10^{-6}
^{40}K	93	1.26×10^{-6}	1.2×10^{-4}
^{210}Pb	4.1	4.50×10^{-6}	1.8×10^{-4}

Cancer Risks at the Gross Beta MCL

Another way to evaluate whether the MCL is health protective is to assume that drinking water can contain as much as 50 pCi/L of a selected beta particle radionuclide, and calculate the resulting risk. Using the unit risk for drinking water in Table 1 above, the lifetime cancer risk is calculated at the gross beta activity MCL of 50 pCi/L for the five most carcinogenic radionuclides covered by the beta particle/photon activity standard. These selected isotopes are lead-210, iodine-129 and -131, cesium-134, and ruthenium-106. We assumed that each radionuclide was at 50 pCi/L and calculated the lifetime cancer risk using the unit risk values in Table 1. The results are listed in Table 3. The table shows that the estimated maximum lifetime cancer risk at the MCL is greater than 10^{-3} for lead-210, and at or above 10^{-4} for the others.

Table 3. Cancer Risk at the Gross Beta MCL for Five of the most Carcinogenic Radionuclides Covered by the MCL

Radionuclide	Risk per pCi/L in drinking water	Risk at 50 pCi/L in drinking water
^{210}Pb	4.50×10^{-5}	2.3×10^{-3}
^{129}I	7.54×10^{-6}	4.5×10^{-4}
^{131}I	2.33×10^{-6}	1.2×10^{-4}
^{134}Cs	2.16×10^{-6}	1.1×10^{-4}
$^{106}Ru/Rh$	2.16×10^{-6}	1.1×10^{-4}

The high estimated cancer risk values in Table 3 shows that 50 pCi/L represents much greater than the *de minimis* risk level for each of these isotopes if they should be present at that level. The *de minimis* risk level used by the PHG program is 10^{-6}; hence for the most potent of these isotopes, Pb-210, the corresponding water level would be about 0.22

pCi/L. Actual risk at the 50 pCi/L MCL depends on the particular mixture of isotopes and their cancer risk coefficients. In addition, lifetime cancer risk depends on the time-averaged concentration in water, rather than specific high instances, as reflected by the maximum measured concentrations shown in Table 2.

USE OF GROSS BETA PARTICLE/PHOTON ACTIVITY LEVELS FOR SCREENING

As stated above, the gross beta particle/photon MCL is utilized as a screening tool to protect the public from beta particle sources, and was originally developed to protect against exposure to man-made radiation from fallout. The current levels of fallout radioactivity in public water supplies have declined to almost non-detectable levels, and under ordinary circumstances, the levels of man-made beta/radioactivity are not likely to be high enough to represent a concern (U.S. EPA, 2003).

There still may be a reason for concern for exceptional circumstances and natural radiation. The U.S. EPA ERAMS (2003) program detected iodine-131 in a very small number of water samples. The cancer risk associated with the maximum value detected for iodine-131 is approximately 1 in a million. In addition, the California gross beta MCL of 50 pCi/L was never exceeded in the California testing program from 1984-2001 (DHS, 2002). The natural beta-emitter lead-210 probably should be included in the gross beta particle/photon measurement or as part of the natural radionuclides measured under the gross alpha scheme. It is derived from radon from the uranium-238 decomposition series. A fraction of the gaseous radon (half-life 3.82 days) seeps from sediment and rock into the air, and through a chain of short-lived daughter elements forms lead-210, which has a half-life of 22.3 years. The lead-210 falls out of the atmosphere and into surface water; it accumulates in soils, lake and ocean sediments, and glacial ice. At the end of the decomposition chain is lead-206, a stable element. Because of this natural, airborne source, lead-210 can be commonly found at trace levels in drinking water.

The beta/photon-emitting constituents in California's drinking water are not fully characterized. Although the man-made beta/photon activity is a minor and diminishing concern in drinking water, U.S. EPA occurrence data suggest that naturally occurring beta/photon radionuclides like potassium-40 and lead-210 are of potential concern. The current gross beta particle/photon screening methodology requires that the beta particle activity derived from potassium-40 be excluded from the overall beta activity, while lead-210 is not routinely evaluated. Potassium-40 is ubiquitous, and lead-210 is very radiotoxic as well as widespread in the environment. Our risk evaluation showed that the risks from lead-210 could greatly exceed the 10^{-4} risk level if the concentration approached the gross beta MCL of 50 pCi/L. It would be more health protective to consider a lower screening level and apply the gross beta particle/photon measurement procedure to target natural beta/photon sources, including potassium-40 and lead-210, or alternatively, natural beta/photon sources could be included under the gross alpha screen, as is done for radium-228. Health risks could be estimated by using specific risk levels as shown in Table 1 for these radionuclides.

Choice of a screening level should consider that screening represents a point estimate, and the sum of activities from a mixture of radionuclides with different risk coefficients.

As a standard (an MCL) is intended to provide health protection against the common radionuclides in water, the discussion above shows that the current approach of using the MCL as a screening threshold of 50 pCi/L is not health protective, and should be reconsidered. Furthermore, the concept of a PHG based on a *de minimis* risk level for some arbitrary mixture of beta/photon emitting radionuclides does not seem useful. Separate PHGs are being developed for the more important beta/photon radioisotopes, including radium-228, strontium-90, and tritium. A PHG has already been published for uranium (www.oehha.ca.gov).

Finally, it should be reiterated that the U.S. EPA does not consider the gross beta concentration of 50 pCi/L to be the MCL. They consider 4 mrem/yr as the MCL and the approximately equivalent gross beta activity of 50 pCi/L to be a screening tool. This radioactivity level is acknowledged by U.S. EPA to represent a lifetime cancer risk in the $10^{-4} – 10^{-6}$ range. California could adopt a comparable approach by specifying that measurement of gross beta is only a screening tool, while adopting a new standard in mrem/yr as the MCL for manmade radionuclides. OEHHA's discussion above addressing the use of a 50 pCi/L standard would apply in this case. That is, OEHHA recommends that the revised standard should consider both natural and man-made sources of radioactivity and a health-protective risk level based on the revised risk coefficients of Federal Guidance Report 13 (U.S. EPA, 1999). OEHHA acknowledges that a 10^{-6} *de minimis* risk level based on the most radiotoxic of the possible isotopes is inappropriate for screening, and suggests the use of a screening level based on radioisotope patterns typical of California drinking water sources.

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