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HEALTH CONSULTATION - NONPOTABLE USE OF URANIUM GROUNDWATER NEAR THE FERNALD ENVIRONMENTAL MANAGEMENT PROJECT

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ATSDR PUBLIC
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REPORT

Health Consultation

FOR

NONPOTABLE USE OF URANIUM CONTAMINATED GROUNDWATER

NEAR THE

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT

FERNALD, HAMILTON COUNTY, OHIO

CERCLIS NO. OH6890008976

FEBRUARY 1996

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Agency for Toxic Substances and Disease Registry
Division of Health Assessment and Consultation
Atlanta, Georgia

Health Consultation: A Note of Explanation

An ATSDR health consultation is a verbal or written response from ATSDR to a specific request for information about health risks related to a specific site, a chemical release, or the presence of hazardous material. In order to prevent or mitigate exposures, a consultation may lead to specific actions, such as restricting use of or replacing water supplies; intensifying environmental sampling; restricting site access; or removing the contaminated material.

In addition, consultations may recommend additional public health actions, such as conducting health surveillance activities to evaluate exposure or trends in adverse health outcomes; conducting biological indicators of exposure studies to assess exposure; and providing health education for health care providers and community members.

This document has previously been released for a 30 day public comment period. Subsequent to the public comment period, ATSDR addressed all public comments and revised or appended the document as appropriate. The health consultation has now been reissued. This concludes the health consultation process for this site, unless additional information is obtained by ATSDR which, in the Agency's opinion, indicates a need to revise or append the conclusions previously issued.

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Prepared by

Agency for Toxic Substances and Disease Registry
Division of Health Assessment and Consultation
Federal Facilities Assessment Branch
Energy Section

SUMMARY

The Agency for Toxic Substances and Disease Registry (ATSDR) asked the Environmental Protection Agency's (EPA) National Air and Radiation Environmental Laboratory (NAREL) to collect and analyze private well groundwater samples in the vicinity of the Fernald Environmental Management Project (FEMP) Site to evaluate whether people using private well water for nonpotable uses might be exposed to hazardous levels of contaminants in the water.

Water classified as potable water is suitable for drinking, cooking, food preparation, and other uses in which people ingest it. Nonpotable water is not suitable for ingestion, but nonpotable water from wells is generally safe for other uses such as laundry, bathing, or watering a garden.

ATSDR has determined that uranium, radon, and other radionuclides in the groundwater do not pose a health hazard to people using the water for nonpotable uses.

BACKGROUND

In 1989, the Department of Energy (DOE) began providing bottled water to some residents in the area near the Fernald site because their sampling had detected elevated uranium concentrations in some private wells [1]. Some residents asked ATSDR if it were dangerous to use their well water for purposes other than drinking [2]. This health consultation presents the results of the analyses NAREL performed on groundwater samples collected from private wells in March 1994 and our evaluation of those results.

RESULTS

NAREL technicians collected 15 water samples from 10 wells around the FEMP site. They also collected one water sample from each of two wells located northeast and northwest of the plant, upstream of the groundwater flow, as background samples. They performed gross alpha and gross beta analyses, gamma spectrometry, and isotopic uranium analyses on each sample. Table 1 presents the results. The gamma spectrometry analysis identifies and quantifies gamma-emitting radionuclides in the sample. The isotopic uranium analyses were done because DOE has reported uranium contamination in the groundwater. Analyses of the background samples would show whether the same radionuclides occur naturally and, if so, at what concentrations. Figure 1 shows the groundwater sampling locations near the FEMP. The

sample numbers on the map correspond to the unique sample numbers shown in Table 1.

We considered two hypothetical situations to evaluate the potential health hazard from nonpotable uses of the groundwater. In the first case, a bathing scenario, we considered dermal contact, accidental swallowing of the water, and inhalation of radon gas that might effuse from the water. In the second case, we considered hypothetical maximum dermal contact and exposure to the water.

We estimated the radiation dose to a person who bathed daily for 30 minutes and remained in the bathroom for 30 additional minutes after bathing, allowing for possibly inhaling radon after bathing. We assumed that this bathing scenario occurred 365 days per year for 70 years. We evaluated the radiation hazard based on immersion in water during bathing, incidental water ingestion (we estimated ingestion of 0.025 liters of water during each bath), and inhalation of radon that might effuse from bath water. We used the highest levels of each uranium isotope and radon measured from all our samples except the background samples. Finally, we also assumed all the radionuclides were in their most soluble forms and were therefore most bioavailable.

Based on the maximum concentrations measured in groundwater the total radiation dose to a person who bathes in this water is 0.0017 millisievert per year (mSv/yr), *including background radiation dose from the water* (see Appendix A for dose calculations.) The International Commission on Radiation Protection (ICRP) recommends limiting public radiation doses to 1 mSv/yr above background levels [3]. The dose that ATSDR calculated, including the background radiation dose, is much less than the ICRP public dose limit.

To assess the maximum possible external radiation exposure a person might receive, we considered the hypothetical case of a person who is in continuous contact with this water for 24 hours each day, 365 days per year. We concluded that radiological contaminants in the groundwater do not pose a public health hazard for external exposures.

There are limitations to our sampling and evaluation: We collected only a small number of private well water samples, and we collected them only once (i.e., we did not return for seasonal samples). We also did not analyze the samples for nonradioactive substances. (Nonradioactive contaminants may be arificially introduced into the groundwater or may ocur naturally.

Nonradioactive contamination can come from well pumps or piping, leaking septic systems, and other waste sources.)

CONCLUSIONS

Based on the data we collected, ATSDR concludes that uranium, radon, and other radionuclides in groundwater in the Fernald area are not a public health hazard to people using the groundwater for nonpotable purposes.

RECOMMENDATIONS

No recommendations.

Figure 1. Groundwater sampling locations near FEMP

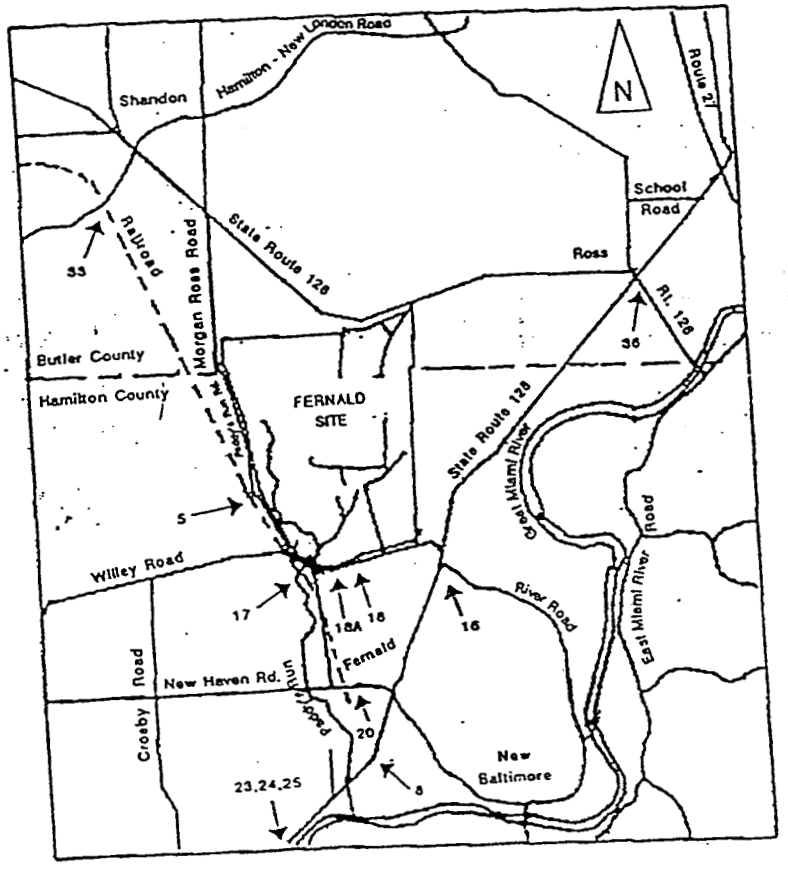

TABLE I

FERNALD GROUNDWATER
MARCH 1994

RADIONUCLIDE[1]	SAMPLE NUMBER																
	5/1	8/1	16/1	16/1D	16/2	16/2D	17/1	18/1	18/2	18/3	18A/1	20/1	23/1	24/1	2/15	33/1*	36/1*
	(pCi/L)																
U-234	0.830	0.180	0.290	0.320	0.260	0.300	0.500	26.900	0.350	0.570	0.140	0.140	2.930	0.120	0.120	0.150	0.520
U-235	0.039	0.001	0.022	0.014	0.028	0.012	0.051	1.100	0.015	0.025	0.006	0.011	0.140	0.012	0.010	0.002	0.031
U-238	0.820	0.120	0.240	0.250	0.150	0.230	0.530	27.100	0.330	0.350	0.120	0.062	2.730	0.062	0.049	0.076	0.360
Rn-222	385	**	**	140	**	**	336	239	252	264	203	119	333	44	82	105	550

[1] Bi-214, K-40, Pb-212, and Pb-214 were detected in some samples, but not within acceptable levels of certainty.
* Background samples
** No data reported for these locations. (NOTE: radon in water information was collected as part of the ATSDR/NAREL indoor radon surveys)

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REFERENCES

1. 1993 Site Environmental Report, U.S. Department of Energy, Fernald Environmental Management Project, June 1994.

2. Trip Report, ATSDR, February 26, 1993

3. Radiation Protection, 1990 Recommendations of the International Commission on Radiological Protection (ICRP), ICRP Publication 60, Pergamon Press, New York, 1991.

APPENDIX A.1: Radiation Exposure and Dose Standards

ATSDR evaluated the radionuclides discussed in this appendix to determine whether exposure to them has public health significance. ATSDR considers several factors in selecting contaminants for discussion: community health concerns, contaminant concentrations, and potential pathways of exposure.

The agency's evaluation approach for radionuclides and other radioactive materials differs from its approach to evaluating nonradioactive hazardous materials. Because of radiation's additive effects on the human body, we calculate a total dose for all exposure routes.

Chemicals released into the environment do not always result in human exposure. People can be exposed to a chemical contaminant only if they breathe, ingest, or touch the contaminant. However, a person can also receive an external radiation exposure (i.e., irradiation by external sources) by just being near contaminated water, soil, or air [1,2].

Several exposure factors influence the health effects associated with exposure: the exposure concentration (how much), the duration of exposure (how long), the route of exposure (breathing, eating, drinking, skin contact, or proximity to gamma-emitting radionuclides), and the multiplicity of exposure (combination of contaminants). Once a person is exposed, individual characteristics -- age, sex, nutritional and health status, lifestyle, and family traits -- influence how the contaminant is absorbed (taken up by the body); metabolized (broken down by the body); and excreted (eliminated from the body). When the contaminant is a radionuclide, the same exposure factors and individual characteristics also apply along with exposure via external irradiation.

ATSDR staff members researched the scientific literature to determine the possible health effects of radionuclides. For information about radiological hazards, they reviewed the International Commission on Radiological Protection (ICRP) publications on the basic principles of radiation protection.

The probability of carcinogenic health effects and severity of noncancerous health effects increases as exposure to radiation increases, although exposure to background levels of radiation naturally occurring in the environment are thought not to produce noticeable health effects in humans [4]. For radiation protection purposes, therefore, the dose due to radiation

exposures above background is calculated as an indicator of potential health effects.

For radiation safety standards, ICRP recognizes three categories of exposure: occupational, public, and medical. For members of the public, ICRP recommends an effective-dose limit (i.e., sum of radiation doses to the body) for skin exposure of 1 millisievert (mSv)(100 millirem [mrem]) above background in a year to protect against carcinogenic health effects and 50 mSv (5,000 mrem) above background in a year to protect against noncancerous health effects [3]. (No adverse health effects have been directly attributed to a radiation exposure at those levels.)

The current ICRP recommendations specify an annual limit on intake (ALI) defined as the amount of a radionuclide that delivers the occupational effective-dose limit from ingestion or inhalation exposure. Occupational annual limit of intake reflects the 50-year average career span of an occupationally exposed person. ICRP recommends using the average lifetime of an individual--70 years--and the public's effective-dose limit, 1 mSv (100 mrem) per year, to determine the public's annual limit of intake by way of ingestion or inhalation. ICRP does not make recommendations for medical exposures. However, the commission does recommend that people receive only necessary exposures and that exposures be limited to the minimum dose necessary for medical benefit to the patient.

APPENDIX A.2: Radiological Evaluation of Fernald Groundwater

Radiation doses usually fall into two categories: internal and external. Internal radiation doses result from exposure to radioactive sources inside the body; external radiation doses result from exposure to radioactive sources outside the body [1].

Whether an exposure contributes to a person's internal or external radiation dose depends primarily on the type of radiation to which a person is exposed. Most alpha particles can not travel far, and the epidermis, the body's outermost layer of skin, prevents their entering the body. Therefore, exposures to alpha particles originating outside the body would not contribute to a person's external radiation dose; however, if an alpha particle source is deposited within the body, it could, depending on its location, contribute to a person's internal radiation dose. Gamma photons can travel long distances and can easily penetrate and irradiate body tissues; therefore, people can be exposed to gamma photons from both external and internal sources. Beta particles may also be responsible for both internal and external radiation doses. They do not penetrate body tissue as easily as gamma photons, however, and that limits the dose from external sources. The total dose is the sum of a person's external and internal radiation doses [1].

ATSDR's quantitative evaluation of exposure from internally deposited radionuclides considers incidental water ingestion while bathing. Investigators calculated the radiation dose by estimating a person's annual intake of water from bathing, multiplying the annual water intake rate (i.e., exposure) by the maximum concentrations of radionuclides found in nearby groundwater (the annual radionuclide intake), and comparing the estimated annual radionuclide intake to the public's ALI,[1] which infers the annual radiation dose to a hypothetical individual.

For external exposures in the Fernald area, ATSDR staff members assumed the primary external source is water and it is evenly contaminated. They define "evenly contaminated" as contaminated with the maximum amounts reported by the Environmental Protection Agency (EPA) National Air and Radiation Environmental Laboratory (NAREL) during the study period. ATSDR investigators performed the quantitative evaluation of exposure to bathers by multiplying the external dose coefficient (see Table A.2.4) for each

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[1] The public's ALI (Annual Limit on Intake) used here as the annual amount of a radionuclide a member of the public can inhale or ingest which delivers the annual public dose limit of 1 mSv per year (100 mrem per year).

radionuclide found in the groundwater by its maximum concentration and the time spent bathing. ATSDR also estimated the external radiation dose due to continuous immersion in the Fernald groundwater.

Radionuclide Concentrations in Fernald Area Groundwater

The remedial investigation (RI) for Fernald shows that in some areas, concentrations of uranium in groundwater are higher than expected background. That situation indicates uranium contamination.

U-238 and U-235 uranium in soil are usually in radioactive equilibrium with members of their decay series. However, radioactive equilibrium for the decay chains may not exist in water because of different water solubilities and different hydrological conditions. Therefore, ATSDR evaluated only the dose contribution from those radionuclides NAREL measured in groundwater and not the contribution from other members of the decay chain. Table A.2.1 shows the maximum radionuclide concentrations in groundwater.

Table A.2.1. Maximum Reported Radionuclide Groundwater Concentrations[1]

Radionuclide	Maximum Groundwater Concentration (pCi/L)[2,3]
U-234	26.9
U-235	1.1
U-238	27.1
Rn-222	385

1. Excluding background locations.
2. To convert picocuries per liter (pCi/L) to becquerels per liter (Bq/L), multiply by 0.037.
3. Values reported by NAREL.

Radiation Exposure Calculations

Bather

ATSDR investigators considered an exposed population of persons who bathe in groundwater containing uranium and radon. The bathers may be exposed to water, air, and external radiation to

their body and skin[1]. Because a person is usually partially immersed and in direct contact with water while bathing, ATSDR is particularly concerned about adverse effects to the skin. ATSDR also considered the effects of grooming after bathing in the bathroom with the doors and windows closed, which would maximize inhalation exposure.

ATSDR investigators assumed that people bathe once per day for 30 minutes per day, 365 days per year. They also assumed that bathers remain in the bathroom, grooming, with the doors and windows closed for an additional 30 minutes per day. They believe it is possible for the bathers to ingest bath water incidentally. Therefore, they used an incidental water ingestion rate of 25 milliliters (mL) per bath (our estimate of 1/3 of a mouthful). ATSDR believes it is possible for bathers to inhale radon escaping from bath water into air and used a breathing rate of 0.6 m^3 per hour (m^3/hr) [5].

Bather: water, air[2], and external irradiation (body and skin)

water (ingestion of 1/3 mouthful of water ≈ 25 mL/bath):

$$25 \frac{mL_{ING}}{bath} \times 1 \frac{bath}{day} \times 365 \frac{days}{year} = 9{,}125 \frac{mL_{ING}}{yr}$$

external irradiation (submersion in water):

$$30 \frac{minutes}{bath} \times 1 \frac{bath}{day} \times 365 \frac{days}{yr} \times 60 \frac{seconds}{minute} = 657{,}000 \frac{sec}{yr}$$

To determine the total amount of internal radionuclide intake, ATSDR scientists multiplied the annual incidental water ingestion rate by the maximum concentration of radionuclides measured in groundwater to establish the amount of each radionuclide ingested per year while bathing. The table below contains the results. We do not generally perform radon inhalation dose calculations. Instead, we typically use risk estimates as the basis for health determinations. Therefore, ATSDR followed EPA methodologies concerning inhalation exposure to radon transferred from water to air [6].

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[1]The calculation of dose to the body does not include the dose to one's skin, therefore skin dose is calculated separately.

[2]The inhalation pathway contains only one radionuclide, radon, and exposure to radon is evaluated using an EPA methodology which differs from typical exposure/dose calculations.

Table A.2.2. Total Annual Amounts of Radionuclide Exposure Through Incidental Ingestion of Bath Water.	
Radionuclide	Bather Intake (Bq/yr)
U-234	9.08
U-235	0.37
U-238	9.15
Rn-222	3,513[1]

1. The units for Rn-222 intake are in pCi/yr because the Rn-222 dose conversion factor is expressed in mrem/pCi.

ATSDR also considered a population of exposed people who are immersed in Fernald groundwater containing uranium, radon, and other radionuclides.

Immersed individuals may be exposed to external radiation to their body and skin.

ATSDR evaluated a worst-case scenario, in which immersion was continuous (24 hours per day for 365.25 days per year).

Immersed individual: external irradiation (body and skin)

external irradiation (submersion in water):

$$24 \frac{\text{hrs}}{\text{day}} \times 365.25 \frac{\text{days}}{\text{yr}} \times 60 \frac{\text{minutes}}{\text{hr}} \times 60 \frac{\text{seconds}}{\text{minute}} = 31{,}557{,}600 \frac{\text{sec}}{\text{yr}}$$

Radiation Dose Calculations

Internal Radiation Dose

The ICRP recommendations specify an ALI, defined as the amount of a radionuclide that delivers the occupational effective-dose limit, 20 mSv (2,000 mrem) per year, from ingestion or inhalation exposures. The ALI calculation reflects the average career span of an occupationally exposed person: 50 years. ICRP recommends using the average lifetime of an individual (70 years), and the public's effective-dose limit, 1 mSv (100 mrem) per year, to determine the public's ALI (PALI) by way of ingestion or inhalation.

These calculations are based on the ICRP's finding that using an integration period of 50 years versus 70 years is adequate for

members of the public because the correction factor could be no more than 70/50 (1.4) [7]. Therefore, to be conservative on behalf of the public's health (i.e., maximize the radiation dose per intake), ATSDR applied the 1.4 conversion factor to 50-year doses to project 70-year doses. The result lowers the annual amount members of the public can safely ingest or inhale.

The general formula for the ALI is as follows:

$$ALI = \frac{\text{annual effective dose limit (20 mSv/yr)}}{\text{committed effective dose in 50 years}}$$

and the following is the formula for exposures to the public:

$$PALI = ALI/(20 \times 1.4)$$

A person's internal radiation dose is proportional to the amount of radionuclides in the person's body. By calculating the PALIs, ATSDR determined how much of a particular radionuclide delivers 1 mSv/year to the average person. By manipulating that ratio, ATSDR can infer doses for the bathing scenario at Fernald. The table below contains estimates of the internal radiation dose for each radioactive contaminant measured in the groundwater. It shows the annual internal radiation dose resulting from ingestion of bath water.

Table A.2.3. Annual Internal Radionuclide Dose Through Ingestion for Bather.

Radio-nuclide	ALI[1] (Bq)	PALI (Bq)	Dose Conversion Factor (mSv/pCi)	Annual Dose (mSv/yr)
U-234	7×10^5	30,000	n.a.	0.00030
U-235	7×10^5	30,000	n.a.	0.00001
U-238	8×10^5	30,000	n.a.	0.00030
Rn-222	n.a.	n.a.	*3.17×10^{-7}	0.0011
Total				0.00172

1. ALI values published ICRP 60
n.a. = Not applicable
* Radon dose conversion factor calculated using dose to specific organs (6), ICRP 60 tissue weighting factors (3), and the a radiation weighting factor of 20 for the primary mode of decay for Rn-222 (alpha)(3).

The following formula is used to calculate internal radiation doses:

$$\frac{1\ \text{mSv/yr}}{\text{PALI}} \times \text{annual intake of radionuclide} = \text{dose.}$$

The example below illustrates calculation of the internal radiation dose through annual U-234 intake.

Bather (U-234)

$$\frac{1\ \text{mSv/yr}}{30{,}000\ \text{Bq/yr}} \times 9.08\ \text{Bq/yr} = 0.000303\ \text{mSv/yr}$$

Estimates of Risk From Inhalation of Radon

Because radon is a radioactive noble gas, no ALI values exist for inhalation of radon. Therefore, ATSDR used the EPA methodology outlined in its "Report to the United States Congress on Radionuclides in Drinking Water" [6]. To evaluate exposure due to inhalation of radon escaping from a water source, EPA uses the following equations:

$$\text{risk} = \text{exposure}_{INH} \times \text{risk factor}$$

where

$$\text{exposure}_{INH} = \text{exposure}_{air} \times \text{volume of air breathed}$$

and

$$\text{exposure}_{air} = \text{radon concentration in water} \times \text{water to indoor air transfer coefficient} \times \text{radon daughter equilibrium factor} \times \text{room occupancy factor.}$$

The report also provides values for the indoor air from water transfer coefficient (1/10,000), the radon daughter equilibrium factor (0.5), and the lifetime risk factor per pCi of inhaled air (4.7×10^{-13}). Using information from the exposure scenario, the bathroom occupancy factor for a bather is 1/24 (i.e., one hour or bathroom occupancy for every 24 hours in a day).

Thus, the following formula yields exposure_{air} due to inhalation of radon transferring from water to air:

$$\text{exposure}_{air} = 385\ \text{pCi/L} \times 1/10{,}000 \times 0.5 \times 1/24 =$$

$$8.02 \times 10^{-4}\ \text{pCi/L.}$$

The exposure to a bather can be estimated through calculation of how much radon the bather inhales. According to the EPA Exposure Factors Handbook [5], the amount a person breathes while engaged in light activity is 0.6 m^3 per hour (m^3/hr). Based on that assumption, ATSDR staff members believe a bather may inhale 600 L of air in an hour (i.e., 0.6 m^3/hr x $(100)^3$ cm^3/m^3 x 1 mL/cm^3 x 1 L/1,000 mL).

The formula above yields the following calculation:

$$\text{exposure}_{INH} = 8.02 \times 10^{-4} \frac{\text{pCi}}{\text{L}} \times 600 \frac{\text{L}}{\text{hr}} \times 1 \frac{\text{hr}}{\text{day}} \times 365 \frac{\text{days}}{\text{yr}}$$
$$= 176 \text{ pCi/yr},$$

and the following risk:

$$\text{risk} = 176 \text{ pCi/yr} \times 70 \text{ yrs} \times 4.7 \times 10^{-13}/\text{pCi} = 5.78 \times 10^{-9}.$$

ATSDR does not consider this risk a public health hazard.

External Radiation Dose

External dose calculations were also evaluated for bathers and for individuals continuously immersed in water. In these calculations, ATSDR assumed the groundwater was homogeneously contaminated with the maximum radionuclide concentration reported by NAREL. Federal Guidance Report No. 12 dose conversion factors for immersion in water containing radionuclides were used to estimate the bather's external radiation dose [2]. The dose factors are calculated for an infinitely large volume of water; therefore, they overestimate the actual dose received from any immersion activity. Table A.2.4 contains tabulations of estimates of external radiation doses for the body and skin, and Table A.2.5 contains a summary of radiation doses for each exposure scenario.

Table A.2.4.
Annual Exposure Hours Per Year (hrs/yr) and External Radiation Dose (mSv/yr).

Radio-nuclide	External Dose Conversion Factor for the Body (Sv/sec Bq/m^3)	External Dose Conversion Factor for the Skin (Sv/sec Bq/m^3)	Time Exposed per Year (sec/yr)	External Radiation Dose for the Body (mSv/yr)	External Radiation Dose for the Skin (mSv/yr)
Bather					
U-234	1.75×10^{-20}	9.55×10^{-20}	657,000	1.14×10^{-8}	6.24×10^{-8}
U-235	1.59×10^{-17}	1.89×10^{-17}	657,000	4.25×10^{-7}	5.05×10^{-7}
U-238	7.95×10^{-21}	6.83×10^{-20}	657,000	5.24×10^{-9}	4.50×10^{-8}
Rn-222	4.16×10^{-20}	4.90×10^{-20}	657,000	3.89×10^{-7}	4.59×10^{-7}
Total				8.31×10^{-7}	1.07×10^{-6}
Immersed individual					
U-234	1.75×10^{-20}	9.55×10^{-20}	31,557,600	5.50×10^{-7}	3.00×10^{-6}
U-235	1.59×10^{-17}	1.89×10^{-17}	31,557,600	2.04×10^{-5}	2.43×10^{-5}
U-238	7.95×10^{-21}	6.83×10^{-20}	31,557,600	2.52×10^{-7}	2.16×10^{-6}
Rn-222	4.16×10^{-20}	4.90×10^{-20}	31,557,600	1.87×10^{-5}	2.20×10^{-5}
Total				4.00×10^{-5}	5.15×10^{-5}

The following formula is used to calculate external radiation doses:

dose = external dose coefficient x water concentration x

exposure time x conversion factors.

The following example shows the calculation of a bather's external dose from annual external exposure:

Bather (U-234)

$$1.75 \times 10^{-20} \frac{Sv}{Bq\ sec} \times 995.3^{1} \frac{Bq}{m^3} \times 657{,}000 \frac{sec}{yr} \times 1{,}000 \frac{mSv}{Sv}$$

$$= 1.14 \times 10^{-8}\ mSv/yr$$

The internal dose is much greater than the external dose for bathers, so adding the two is not substantially different from the internal dose alone. Therefore, the external dose is insignificant.

In both exposure scenarios, bathers and individuals who are continuously immersed in water, the doses to the body, including background are less than the recommended limit of 1 mSv per year [3]. Adverse Health effects associated with those doses are unlikely. (Note: this assumption does not reflect the radon exposure, because it was evaluated using a risk-based method, not a radiation-dose based method.)

In both exposure scenarios, the total dose to the skin is much less than the recommended 5 mSv per year [3] of the ICRP for limiting public exposures to the skin from radioactive material. Therefore, health effects associated with those exposures are unlikely, and the exposures do not pose a public health hazard.

Finally, considering the combined exposures (including the radon), ATSDR investigators believe that no adverse health effects are likely, and that the exposures do not pose a public health hazard.

Table A.2.5. Summary of Radiation Doses.

Exposed Person	Internal Dose (mSv/yr)	External Dose (mSv/yr)	Total Dose[1] (mSv/yr)	Skin Dose (mSv/yr)
Bather	0.00172	0.000000831	0.00172	0.00000107
Continuously Exposed Individual	n.a.	0.00004	0.00004	0.0000515

1. Note, the total dose to the body does not include the dose to the skin.
n.a. = not applicable

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[1] $26.9 \frac{pCi}{L} \times \frac{1\ L}{1{,}000\ mL} \times \frac{1\ mL}{1\ cm^3} \times (100)^3 \frac{cm^3}{m^3} \times 0.037 \frac{Bq}{pCi} = 995.3 \frac{Bq}{m^3}$

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