Non-cancer effects:
- Thickening and discoloration of the skin
- Stomach pain, nausea, vomiting, diarrhea
- Numbness in hands and feet
- Partial paralysis
- Blindness

Cancerous effects:
- Cancer of the bladder, lungs, skin, kidney, nasal passages, liver and prostate

Arsenic - Drinking Water Standards in the United States
- Maximum Contaminant Level = 0.010 ppm (10 ppb)
- Maximum Contaminant Level Goal (MCLG) = 0 ppm
  - The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety and are non-enforceable public health goals.
- Arsenic (As) drinking water standard
  - Before 2001 = 50 ppb
  - After 2001 = 10 ppb (systems had to comply by 2006); still debated - some think it’s too strict, while others think it’s too high. New Jersey set its own MCL = 5 ppb
- Web page: http://water.epa.gov/drink/contaminants/index.cfm

Arsenic problems in groundwater in SE Asia
- Widespread occurrence of hazardous pathogens in rivers and ponds prompted national and international agencies to help install tube wells (groundwater) for drinking water and irrigation supplies in Bangladesh
- 10 million new domestic wells drilled in last 45 years

PROBLEM: many wells contain high arsenic. "Worst mass poisoning of a human population in history (Smith et al., 2000)"
- Arsenic concentrations are patchy - although there are general trends, not necessarily easy to predict where you might find high arsenic wells
Arsenic problems in groundwater in SE Asia

- Over 100,000 people in Bangladesh have already developed skin lesions
- Many more are at risk for developing arsenic-related illnesses, including cancer.

Elements, April 2006

Concentration of arsenic in well waters with depth

- In general, arsenic is lowest at the surface (in near-surface groundwater and surface waters), and in the deepest wells (>~50 m)
- Highest arsenic is found in mid-depth wells (from ~10 to 50 m); however, there is significant variability (spatially and with depth)

J. McIntosh - UA-HWR (2012)

Relationship between arsenic (As) and iron (Fe) in sediments

- Arsenic (As) is adsorbed onto iron (Fe) hydroxide minerals (stable in oxic groundwater)
- Mechanisms of arsenic release into solution are still under investigation

Main hypothesis: under anoxic conditions, arsenic is released to solution by microbial reduction of iron minerals

Figure 1. Arsenic concentrations in ground water of the United States.
Issue with private wells?

- Public supply wells are regularly tested for contaminants, including metals (e.g., Arsenic); if contaminants are found - they are removed to meet federal standards.
- Private wells belong to individuals (~60 million people in US) - not regulated by the government - it's up to well owner to have their well tested.
- Problem is that people rarely have their wells tested; if they do, they often only test for bacteria; and, most people only test their wells if there's an issue with odor or taste.
- Arsenic doesn't have a TASTE!
- Recommend that private well owners have their well water tested for a suite of metals (including arsenic, manganese, uranium, boron), and other potentially naturally-occurring contaminants (e.g. radium)
- Arsenic test costs ~$30; full suite of metals ~$100
- Cost to remove arsenic from drinking water: ~$1,200 to $3,000

Scientific American article by Marla Cone, 10/3/2011

Montezuma’s Well - Source of Recharge & Arsenic?

- Montezuma Castle National Monument - Verde Valley, north of Phoenix
- Sink hole; collapsed travertine dome partially filled with water
- 1.6 million gallons/day of water flow through four vents at the bottom

Early Native Americans used Montezuma well water for agricultural irrigation

Water contains high levels of carbon dioxide, arsenic (157 ppb), and other chemicals
- Toxic to fish at bottom of well, but microorganisms can thrive
- Question of where the high-arsenic water in the well originated

Figure 1. Location and details of study area overlain on geologic map by Weir and others (1986) with hillshade elevations. (Yellow/black dots are towns, blue dots and circles are springs.)
Collecting water sample from vents at bottom of well

Montezuma’s Well - USGS study

Johnson et al. (2011)

Geologic Cross-section of Area

Source and flowpaths of Montezuma Well water

EXPLANATION

Artesian, young beaded (4-16 Ma)
Tv: Tertiary Yavapai Formation
Tv: Tertiary Verde Formation
Tv: Sansa formation in the Tertiary Verde Formation
Tv: younger beaded and young beaded in the Tertiary Verde Formation
Ht: Hualapai in the Tertiary Hualapai Formation
Pp: Permian Puebloan Formation
Ps: Permian Tonto Shale and Penquash Sandstone
Ps: Permian Sonoita Formation
Ps: Permian and Pennsylvanian Sonoita Sandstone
Ms: Mississippi River Siltstone
Ms: Mississippi Redbed Limestone
Dm: Devoan Martia Formation
Ct: Canyons Tiptonia Sandstone
Xa: Early Pliocene basement rocks, undifferentiated

✓ Geochemical and isotopic tracers in Montezuma well water show that:
  * Water was recharged at high elevations up on the Mongollon Rim (evidence from: oxygen and hydrogen isotopes)
  * Water flowed through the Redwall Limestone (karstic/highly permeable aquifer) dissolving arsenic and other metals (evidence from: strontium isotopes; rock composition; no detectable tritium and low radiocarbon)
  * Water was forced back up to the surface from great depth by an impermeable volcanic plug (shown in orange); mixed with deep seated brines and CO2 source

Arsenic in Indian Water Tables Can Cause Diabetes, Other Illnesses

By Terri Hanson October 20, 2011

✓ Arsenic (natural, bedrock sources) and uranium (active/abandoned/reclaimed mines) are major water quality concerns

✓ Navajo Tribal Utility Authority is the only provider of drinking water for the reservation that meets Safe Drinking Water Act

✓ Although utility is extending its system; 1/4 of population using unregulated water sources (including livestock wells)

✓ Community development group - “Forgotten People” – helping to draw attention to water quality problems. In 2010 advocacy resulted in the Navajo Nation issuing a “Declaration of Public Health State of Emergency” in Black Falls/Box Springs (AZ) because all water sources in the area had arsenic and uranium above EPA standards.
Artesian levels in Tucson groundwater

- Higher As levels in groundwater near the Tucson Mountains and to the south
- Thought to be related to source of sediments (sands and gravels) in aquifer
- Tucson Mtns = volcanic rocks
- Copper Porphyry deposits in area (sulfide minerals that contain arsenic)
- Sediments from granitic rocks (Santa Catalina Mtns) generally have low arsenic

Spencer (2000) AZ Geology

Natural Radioactivity in Groundwater

- Radioactive decay emits radiation (alpha, beta and gamma particles)
- Collision of alpha particles with human and animal tissue can cause tissue damage and lead to cell mutation and cancer

Ingredients for radioactivity in groundwater:

1. Geologic source of radioactive elements (uranium, thorium, and potassium) - typically sandstones and granite
2. Right chemical conditions in groundwater (pH, salinity, temperature, and oxygen levels) to keep radium in solution (otherwise will adsorb onto clay and oxide surfaces)
3. Physical release of radioactive elements from minerals into water ("recoil")
Health effects of Radium & Radon

- Epidemiological studies have found an association between bone cancer and elevated radium levels in drinking water.

- 2003 study by New Jersey Dept of Health found that men in southern New Jersey drinking high Ra water had a 3x higher chance of developing bone cancer.

- Radium replaces calcium in bones, radioactivity degrades marrow and can mutate bone cells (leading to cancer).

- Radon (product of radium decay) = second leading cause of lung cancer in US (smoking = #1).

Radium Levels Exceeding EPA MCL

- High Radium (Ra-224, Ra-226, Ra-228) in groundwater wells in midwest from Cambrian-Ordovician sandstone & dolomite aquifers.

- New Jersey - Triassic Basin sediments - low pH and high NO3 groundwater from agricultural return flows. Increased H+ displaces Ra from adsorption sites on clays.

Occurrence and geochemistry of radium in water from principal drinking-water aquifer systems of the United States


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Radium Levels Exceeding EPA MCL

- High radium in OK/KA/MO/AR correlated with high salinity groundwater
- High radium correlated to anoxic conditions (no dissolved oxygen)
  - In oxic conditions, radium is thought to adsorb onto manganese oxide minerals
  - Under anoxic conditions, manganese oxides are unstable and radium can be released

Accumulation of radon gas in closed spaces can be a health problem
- Radon gas is a significant cause of lung cancer
- Houses are important exposure locations because of time spent in home
- Inhalation and ingestion of radon-rich water may be a health risk, but direct inhalation of radon gas is bigger problem
- When high radon-groundwater supply is used in house, radon can also get into house via showering, dishwashing, clothes washing and sink use