REMOVAL OF URANIUM FROM DRINKING WATER

Catherine Rankin
Undergraduate Student, Civil Engineering
New Mexico State University

SUMMARY

Uranium contaminated drinking water is a common problem, particularly in the western United States. Federal regulations limiting the amount of uranium in drinking water do not exist. Proposed regulations would limit uranium concentration to 10 picocuries per liter (pCi/l) or 15 micrograms per liter (μ g/l). If these regulations are accepted and enforced, many communities will be forced to remove the uranium from their drinking water supplies.

Removal of this radioactive element produces the new problem of radioactive waste disposal. The physical form of this waste and the longevity of uranium cause difficulties in formulating a waste disposal plan.

The three disposal alternatives proposed in this report are dilution/release, reuse or resale, and burial. The disposal alternative chosen naturally will be based on economic feasibility. In this case, dilution/release is easily the least expensive alternative. However, the choice also must be based on environmental acceptability. Each participating community will have unique drinking water and waste characteristics. For this reason it is not possible to prescribe one solution to the problem. Each community must consider its situation and choose the optimum plan on that basis.

INTRODUCTION

More than 80 percent of the drinking water in the United States is supplied by ground waters (Pienciak 1983). The quality of ground water for drinking purposes is dependent on its mineral and biological content, which varies widely from source to source. It appears that all ground

water contains at least some dissolved uranium. Little is known about the tolerance levels or effects of injesting low levels of uranium and thus, no national regulations for a maximum concentration level currently exist. It is assumed in the scope of this paper that uranium concentrations in excess of $15\mu g/l$ should be removed or reduced. A removal process will result in the generation of a radioactive waste.

The purposes of this report are:

1. to present uranium contaminated drinking waters as a problem,
2. to explain the uniqueness of the problem of managing uranium waste,
3. to present alternatives for the management of this particular waste, and
4. to recommend a management procedure based on the criteria and alternatives presented.

URANIUM REMOVAL

Uranium is an alpha-bearing radionuclide. For the purpose of this EPA funded project, uranium will be removed from drinking water supplies when the concentration is in excess of $15 \mu g/l$ (Simon 1980). Thus, alpha-bearing waste will be generated. Two methods are being investigated to achieve either removal or a reduction in concentration. Various forms of waste will result.

Removal Methods

Ion exchange is the first and most efficient removal method. This method removes about 98 percent of the uranium (Lee 1982). The water is filtered through a column of anion exchange resin. Uranium is a strongly negatively charged ion at normal pH values. As it passes water through the column, chloride ions are released by the resin in exchange for uranium. The resin is regenerated with a small volume of very concentrated salt solution of sodium chloride. This time, the resin will release the uranium in exchange for the chloride due to the high chloride concentration. Now the extracted uranium is concentrated into a small volume of regenerant liquid. This concentrated liquid waste must be disposed of in some manner.

135

The second removal technique is chemical clarification. Chemical coagulants form a charged gelatinous floc which is very pH dependent (Kump 1983). Uranium concentration can be reduced with this water treatment process. The addition of either aluminum sulfate (alum) or ferric chloride causes coagulation. The efficiency of this process will vary from 40 to 99 percent, depending on pH and coagulant dosage. The waste from this process will be in the form of a sludge. One disadvantage associated with chemical clarification is that the pH adjustment must be made in order to achieve maximum uranium reduction.

Uranium Concentration Levels

It appears that most ground waters contain some uranium. The concentration of uranium in natural waters is typically much higher in the western United Stated than in the rest of the country.

The calculations within this report are based on "elevated" uranium levels in New Mexico drinking water supplies (Appendix I). The definition of "elevated levels of uranium" is based on the proposed federal regulations of 10 pCi/l uranium or greater (Pienciak 1983). Furthermore, the calculations are based only on the "larger water systems" in New Mexico, which are defined as systems serving 1,000 people or more (Pienciak 1983).

The majority of the New Mexico water systems that meet the criteria mentioned range in concentration from 10.5 to 28 pCi/l. This range is equivalent to 15 to 42 μg/l (Appendix I). The average state value, based on these wells, is approximately 6 μg/l of uranium (Appendix I). An extremely high concentration has been found in a New Mexico State University well (NMSU #8). The uranium concentration in this well is about 165 μg/l. This value was not included in the state average.

Concentrated liquid or liquid/slurry waste results from the ion exchange method. A powdered or cake waste also can be obtained by heat application. It is assumed that the resin is capable of cleansing 3,500 liters of raw water per liter or resin before the resin must be regenerated using 1.5 liters of regenerant fluid. Accordingly, the waste concentration based on the extreme (NMSU #8) will be approximately 380 milligrams per liter (mg/l). The waste concentration from the average New Mexico well would be approximately 50 mg/l.

Sludge waste would result from a chemical clarification procedure. Using ferric chloride as a coagulant, the waste resulting from purifying the extreme uranium concentration would be approximately 2.72 mg U/kg sludge. The state average uranium concentration in sludge resulting from this coagulant would be 0.43 mg U/kg sludge (Appendix II).

UNIQUE PROBLEM OF URANIUM WASTE MANAGEMENT

Uranium is a long lived alpha-bearing element. The uranium waste generated by this project is not part of the nuclear fuel cycle. By these criteria, the waste focused on in this report would be classified as low-level waste. Current low-level waste management and disposal methods are geared toward wastes that remain toxic for a few hundred years at most. The half-life of uranium is 4.5 billion years (Wededohl 1978). For example, if 100 grams of uranium-238 were stored in a box in the year 1492, the amount of Uranium-238 remaining in 1983 would be 99.999999 grams. It is impossible to predict risks involved with disposal over such a long period. The disposal problem becomes even more complicated because the management technique must not only provide low risk to the environment but remain economically feasible for the small waste volumes created.

URANIUM WASTE MANAGEMENT/DISPOSAL ALTERNATIVES

Conditions to be included in the consideration of disposal methods and management procedures are as follows:
1. Food and water supplies should not be contaminated by an excess or radionuclides.
2. Minimal risk to man from exposure to radiation levels will be above safe tolerance levels.
3. Access to any mineral wealth above or below ground will not be adversely affected (Simon 1980).

Numerous waste disposal alternatives are available. However, some methods do not meet the physical requirements of the waste, while others

lack either technical or economical feasibility. Three alternatives that meet both the physical and feasibility requirements will be considered in this paper.

Dilution and Release

One alternative is to dilute and release the uranium concentrated salt solution back into the environment. According to the New Mexico Water Quality Control Commission Regulations (Sec. 3-103) the allowed concentration of uranium to be returned to the environment is 5 mg/l (Perkins 1980).

A concentration of 380 mg/l of uranium per liter of waste fluid would be generated from the "worst case." In order to reduce this concentration through dilution to 5 mg/l, a dilution factor of 75:1 is necessary. A usage rate of 150 gallons of water per day, per person, was assumed. This would result in a total waste volume of about 65 gallons per day, per 1,000 people generated by an ion exchange unit (Appendix III). Under these conditions, approximately 4,400 gallons of uranium-free water per day per 1,000 people would be needed for dilution purposes. The 4,400 gallons of dilution water needed for every 150,000 gallons distributed, amounts to 3 percent of the total water treated. On the state average, the waste concentration of 60 mg/l, requires a dilution factor of 12:1. One-half of one percent of the total volume of treated water will be used for dilution.

The process of dilution and release is mechanically simple. The waste can be diluted and drained into the municipal sewer system simultaneously. Any intent to release the waste into the environment must be brought to the attention of environmental authorities. The procedures must be in accordance with the Water Quality Control Commission Regulations and Hazardous Waste Management Regulations (Goad 1983). The primary concern with this alternative is that the uranium, being turned out into the environment may enter another municipality's water treatment facility downstream.

Reuse or Resale

A second alternative would be to ship liquid/slurry waste to a uranium mill where the waste could be processed along with the incoming

ores (Kump 1983). Several steps would be involved in this process including collection, intermediate storage, shipment, and possible packaging of the waste.

The liquid waste is a concentrated solution of uranium salt. The uranium can be precipitated from the solution either chemically or physically (heat). Because the regenerant solution is sodium chloride, sodium hydroxide can be added to form a precipitate of sodium diurinate (Waligora 1984).

Intermediate storage will require a holding tank to store the waste until a large enough volume is collected for a shipment. This storage will require licensing and a permit from the State Hazardous Waste Management Division and approval of the Radiation Protection Bureau (Steward 1983). The alpha particle has a very low penetration factor. Since uranium is an alpha emitter, a steel or fiberglass tank probably would be the simplest solution to intermediate storage. Based on 5,000 shipments and depending on population size and use of the well, the storage period will range from a minimum of one and one-half weeks to two and one-half months. One well could serve a community with a population ranging from 1,000 to 10,000 people. Storage costs include the initial cost of tank construction and any maintenance required thereafter. The current estimated construction cost of steel tanks is about 25 cents per gallon of volume. The construction cost for a 10,000 gallon holding tank would be about $2,500.

The next stage of this alternative is shipment. Two mills are currently operating in the United States, both of which are located in northern New Mexico. The shipping distances to these sites would be fairly short and feasible for most of New Mexico, Colorado and Arizona. The risk associated with accidents during shipping and storing the waste must be considered. Licensing by the State Hazardous Waste Management Division would be required for shipment on public roads and highways (Stewart 1983). The uranium mills mentioned operate specially designed trucks which are licensed to transport this liquid/slurry.

When considering sale or reuse of the ground water waste, several possible financial arrangements might be feasible (Sloan 1983). The

limiting factors, however, will be the concentration and volume of the waste. It is conceivable that the uranium mill would split the shipping costs with the municipality. It might also be possible for the municipality to receive royalties from the sale of its uranium. Even if a cost sharing or a royalty arrangement is made, the operating costs of this alternative greatly will exceed those of the dilution alternative. Therefore, it is necessary to make a decision based on the involved risk compared to the extra costs of each alternative.

Disposal through Burial

The third choice available for either liquid or a sludge waste disposal is storage or burial. Collection, intermediate storage, shipment, and a solidification and/or volume reduction process must be included before shipment to a burial site. A solidification process could be implemented for either a liquid or sludge waste. Solidification can be achieved by several methods.

In-drum solidification is one process now being used by the Department of Energy (Bucholtz 1983). The waste (either liquid or sludge) is put into drums. Cement is added and the drums are then sealed and tumbled for mixing.

Vermiculite also is used for solidification of sludge or liquid waste. Waste is added to vermiculite filled drums. The vermiculite will expand and incorporate the waste in its matrix (Bucholtz 1983).

A vacuum filtration method will solidify sludge waste as well as reduce its volume (Bucholtz 1983). The vacuum filtration system produces sludge cakes which can be packaged and shipped to a burial site.

Heat can be used to drive off the water after precipitation of an ion exchange waste. The result will be a yellow cake or powdered sodium diurinate (Waligora 1984). However, this process is very expensive and energy intensive. Because the solid waste form presents a much smaller shipping risk compared to the liquid waste, licensing would be easier to obtain. It is difficult to assess costs because the solidification processes are relatively new.

These high cost facilities are located long distances from most burial sites. Several southwestern and midwestern state legislatures

(including New Mexico's) are currently considering a bill to form a
compact among themselves for a radioactive waste burial site. If the
bill were to pass, each state would take its turn providing waste burial
facilities for a determined period of time. Such a site should greatly
reduce shipping costs involved in this alternative. Because of the
shipping distances and management procedures, storage or burial of the
waste would likely be the most expensive disposal alternative.

CONCLUSION

Uranium waste presents unique disposal problems because of its
longevity. Economic factors also complicate the choice of a disposal
alternative. For a large percentage of municipalities that have uranium
in their drinking water supplies, the uranium concentration is relatively
low. In these cases, it may not be economical to dispose of the waste by
shipment to mills or burial facilities.

In other cases, however, the uranium concentration may be quite high,
or several ground water systems in one municipality or one area may
contain uranium concentrations. In these cases where a large volume of
waste feasibly could be produced, it may be more advantageous to consider
shipping the waste to a mill or a disposal site. Large volumes of waste
also would cause the alternative of dilution and release to be less
environmentally desirable.

Uranium waste produced by upgrading drinking water must be disposed
of in some manner. The manner will be unique to each community based on
local concentration, the size and location of the community, and local
economic factors.

Three alternatives have been presented in this report. One may be
more acceptable than another to various communities. Other alternatives
may become available as research and development continues. Whichever
means of disposal is chosen, it must not only be economical, but more
importantly, it must be environmentally acceptable.

REFERENCES

Bucholtz, Jerry, November 1983. Personal communication.

Goad, Maxine (EID, Water Quality Control Commission), August 1983.
     Personal communication.

Kump, Dave (Kerr-McGee Uranium Mills), August 4, 1984. Personal
     communication.

Lee, S. Y., White, S. K., and Bondietti, E. A.(Environmental Scientists),
     September 1982. "Methods of Removing Uranium from Drinking
     Water--II. Present Municipal Water Treatment and Potential Removal
     Methods," EPA-570/9-82-003, pp. 20-25.

Perkins, Betty L., and Goad, Maxine, July 1980. Water Quality Data For
     Discharges from Uranium Mines and Mills in New Mexico, New Mexico
     Environmental Improvement Division, pp. 27-28.

Pienciak, Richard T., August 1, 1983. "U.S. Water Being Poisoned," Las
     Cruces, Sun-News (New Mexico), p. 1.

Pierce, Steven T. (Environmental Scientist), January 11, 1983. Personal
     communication.

Simon, R. and Orlowski, S. (Editors), 1980. Radioactive Waste Management
     and Disposal, New York Harwood Academic Publishers; Geradi, F. (JRC
     Ispra, Italy); de Marsely, G. (School of Mines, Paris, France);
     Weber, J. (Ministry of Health and Environmental Protection, The
     Netherlands).

Sloan, George (Chief Metallurgist, Kerr-McGee Uranium Mill), August 5,
     1983. Personal communication.

Stewart, Jerry (EID, Radiation Protection Bureau), August 3, 1983.
     Personal communication.

Waligora, Stan (Eberlien), February 10, 1984. Personal communication.

Wededohl, K. H., (Exec. Editor), 1978. Handbook of Geo-Chemistry, New
     York, N.Y., Vol. II/5.

APPENDIX I

Uranium Levels of Selected New Mexico Water Systems

System	Source	Uranium Level (pCi/1)
Dona Ana	Composite	11.2 + 0.8
Espanola	Bond Well	16.2
	El Llano Well	18.9
Lordsburg	Well #1	24.5 + 2.5
	Well #2	28.0 + 2.8
NMSU	Well #8	110 + 6*
	Well #9	23 + 2
Santa Fe	Buckman Composite	12.0 + 1.0
Tucumcari	Well #1	12.6 + 1.3
	Well #4	10.5 + 0.7
	Well #6	10.8
	Well #12	22 + 1
	Well #13	16.9 + 0.8
	Well #17	19.8 + 1.0
	Well #18	15.4 + 1.5
	Well #19	15.4 + 1.5
	Well #20	20 + 1

*NOTE: Tests run in 1979-1980 by the Environmental Improvement Division values are probably a composite of four quarterly samples. (EID, Santa Fe, NM, Steve Pierce, written correspondence, 1983)

Average Uranium Level = 17.32 + 1.5 pCi/1
Worst Case (NMSU #8) = 110 + 6 pCi/1

Convert pCi/1 to mg/1:   666.7 pCi/1 = 1 mg

Average: 17.32 pCi/1 x 1 mg/666.7 pCi = 0.02598 mg/1
= 25.98 µg/1 use 26 µg/1

Worst case: 110 pCi/1 x 1 mg/666.7 pCi = 0.16499 mg/1
= 164.99 µg/1 use 165 µg/1

APPENDIX II

Waste Characteristics and Concentrations

Ion Exchange Removal Method - Uranium Concentrated Liquid Waste

A. Assumption case 1:
    1. 1 liter of resin
    2. 3.5 kliters of raw water are treated before regeneration
    3. Removal efficiency is 98%
    4. Volume of regenerant fluid is 1.5 liters

B. Assumption case 2:
    1. 1 liter of resin
    2. 5.0 kliters of raw water are treated before regeneration
    3. Removal efficiency is 97%
    4. Volume of regenerant fluid is 1.5 liters

*NOTE: Advantage of case 1 assumption; resin will remain effective for a longer period of time.

C. Table I. Waste Concentrations Resulting from Ion Exchange

Bed Vol.	% Removed	Reg. Vol.	U Conc(i)	U conc(f)
Average				
1. 3.5 kl	98	0.0015 kl	26.0 µg/l	60 mg/l
2. 5.0 kl	97	0.0015 kl	26.0 µg/l	84 mg/l
Worst Case				
1. 3.5 kl	98	0.0015 kl	165.0 µg/l	380 mg/l
2. 5.0 kl	97	0.0015 kl	165.0 µg/l	535 mg/l

*Only values obtained using case 1 assumptions will be used for further calculations.

Chemical Coagulation Removal Method - Uranium Concentrated Sludge Waste

A. Assumptions:
    1. Coagulant is Fe Cl, dosage is 20 to 200 mg/l
    2. Percent of Uranium removed is 99%
    3. Solids concentration (floc) before filtration is 3%
    4. Final sludge waste (after filtration) is 50% solids

B. Table II. Waste Concentrations Resulting from Coagulation

	Raw conc.	U removed	Wt of sludge	U conc.
Avg.	26.0 g/l	25.74 µg/l	0.060 kg/l	0.429 mg/l
Worst	165.0 g/l	163.35 µg/l	0.060 kg/l	2.720 mg/l

Example calculation:

Raw water concentration x % U removed = mass of Uranium
26.0 g/l x 99% = 25.74 µg/l

Vol. of water x % solids concentration = Wt of solids
(after initial coagulant dosage)
1 kg/l x 3% = 0.03 kg solids/liter water

Raw water conc. = 165 g/l
165 g/l x 0.99 = 163.35 µg/l removed
0.06 kg sludge will contain 163.35 g of U

% solids after coagulation/% solids after filtration = weight of final
sludge per unit of water
0.03/0.50 = 0.60 kg sludge/liter water

U removed/wt of sludge = U concentration in sludge
25.74 g/l/0.06 kg/l = 0.429 mg U/kg sludge

APPENDIX III

Daily Waste Volumes Generated

Ion Exchange Method
  A. Assumptions:
      1. usage rate = 150 gpcd x 1,000 persons - 150,000 gal/day
      2. for every 3,500 l of water used, 1.5 l of waste is generated
          (see Appendix II)
      3. conversion: 1 l/s = 0.2642 gal/s

Daily volume of waste produced per 1,000 people:

  150,000 gpd x 1.5l/3,500 l = 64.3 gpd/1,000 people

Chemical Coagulation
  A. Assumptions are the same as those use above.
  B. densities: water = 1,000 kg/l
      1. sludge solids = 1,060 kg/l
          (sludge is 50% water and 50% solids)
      2. final sludge = 1 (.5) + 1.06 (.5) = 1,030 kg/l
  C. from appendix II--0.06 kg of sludge is produced per liter of
      water

Daily volume per 1,000 people:

  volume = mass/density
  0.06 kg/1,030 kg/m^3 = 5.825×10^{-5} cubic meters

convert to English units:

  5.825×10^{-5} m^3/0.02832 ft^3/m^3 = 0.0020 ft^3 sludge/l
  (0.0020 ft^3/l) / (0.2642 l/gal) = 0.0079 ft^3 sludge/gallon

daily volume:

  150,000 gal/day x 0.0070 ft^3/gal = 1,168 ft^3 sludge/day
  (1,168 ft^3/day) / (27 ft^3/yd^3) = 43.25 yd^3

Table III. Waste Volumes

U removal method	Daily volume per 1,000 people
Ion exchange	64.3 gallons
Coagulation	1,168 ft^3 = 43 yd^3

149