Attachment B

Pottr-Gertz Consultants, Inc.
9 Rittenhouse Place
Ardmore, PA. 19003
215-896-5353

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PGC Report

A DETERMINATION OF THE MPC_w'S FOR ^{133}Xe & ^{135}Xe IN WATER

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I. Introduction

Xenon-133 and Xenon-135 are radio-noble gases which can be found in power reactor liquid effluents. It is the purpose of this report to determine the Maximum Permissible Concentration in Water (MPC_w) of these radionuclides for the general population.

II. Xenon In The Water Environment

A. Maximum Specific Activities Attainable in Water

The maximum specific activities of Xenon-133 and Xenon-135 attainable in the water environment are functions of solubility and intrinsic specific activities. The concentration of Xenon in water can be determined by Henry's Law. This law states that the solubility of a gas in a liquid is directly proportional to the pressure of the gas above the liquid at equilibrium. Mathematically Henry's Law may be expressed as,

$$C = kP \qquad 1.$$

where C is the weight of gas in the liquid, P is the atmospheric partial pressure, and k is Henry's constant for a given gas and a given temperature. At 0° C and 1 atmosphere partial pressure, 242 ml of Xenon will be soluble in 1 liter of water (1). And, by extrapolation it can be shown that 1 liter of water at 10° C can absorb approximately 210 ml of Xenon at 1 atmosphere pressure. Since the density of Xenon is 5.85 mg/ml (2) Henry's constant at 10° C for Xenon is 1.23 g/l-atm. The mole fraction of Xenon in the atmosphere is ~ 8×10^{-8}(3); therefore, substituting into equation 1,

$$C = (1.23 g/l\text{-}atm)(8 \times 10^{-3}\ atm) = 9.8 \times 10^{-8} g/l \qquad 2.$$

it is found that 1 liter of water can absorb up to 9.8×10^{-8} g/l of Xenon at 10° C.

The intrinsic specific activities of Xenon-133 and Xenon-135 are 1.85×10^5 Ci/g and 2.55×10^6 Ci/g, respectively. As such each liter of water can absorb a maximum of either 1.8×10^{-2} Ci of Xenon-133 or 0.25 Ci of Xenon-135. These values are equivalent to 18 µCi/ml of Xenon-133 or 250 µCi/ml of Xenon -135.

III. Determination of MPC_w

The calculation of an adult MPC_w equal to 5000 mrem/year for the drinking water pathway is based on the following equation (4):

$$MPC_w = \frac{1.3 \times 10^{-6} m R \lambda_0}{f_w(1 - e^{-\lambda_0 t}) \Sigma E_i F_i (RBE)_i n_i} \qquad 3.$$

Each term in this equation is discussed below.

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m - m is the mass in grams of the critical organ. It has been shown that Xenon is concentrated in the body fat approximately ten to twenty times above the level in the blood stream (5). Thus the body fat is considered to be the critical organ; its mass is 10,000 g(4).

R - R is the permissible dose rate to the organ in rems/week. Since the body fat is the critical organ, and since it is distributed through the whole body, R is taken as 0.1.

λ_o - λ_o is the effective decay constant, it is a combination of the physical and biological decay constants. In order to calculate λ_o the biological half life (T_b) must be determined.

$$T_b = \frac{0.693\ mC}{If_w} \quad 4.$$

where,

- m = mass of critical organ = 10,000 g
- C = average tissue concentration = 1.1×10^{-6} g/kg based on equation 1 with k equal to 0.68 g/l-atm at 37.8° C and a concentration factor of 20
- I = average daily ingestion rate = 2.3×10^{-7} g based on a water plus fluid uptake of 2200 cc/day and 300 cc/day of water of oxidation produced in the body, therefore intake is $2.21(9.8 \times 10^{-8}$ g/l) + 0.31(0.68 g/l-atm)(8×10^{-8} atm)
- f_w = 0.95 based on a fraction from GI tract to blood of 1.0 and a concentration factor of 20 in the body fat

$$T_b(Xe) = \frac{0.693(10{,}000)(1.1\times10^{-9})}{(2.3\times10^{-7})(0.95)} = 35 \text{ days} \quad 5.$$

$$T_{eff} = \frac{T_b T_p}{T_b + T_p} \quad 6.$$

$$T_{eff}(^{133}Xe) = \frac{(35)(5.27)}{(35) + (5.27)} = 4.58 \text{ days} \quad 7.$$

$$T_{eff}(^{135}Xe) = \frac{(35)(0.38)}{(35) + (0.38)} = 0.38 \text{ days} \quad 8.$$

$$\lambda_o = \frac{0.693}{T_{eff}} \quad 9.$$

$$\lambda_o(^{133}Xe) = \frac{0.693}{4.58} = 0.151/d \quad 10.$$

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$$\lambda_0(^{135}Xe) = \frac{0.693}{0.38} = 1.82/d \qquad 11.$$

$\underline{t}$ - t is the time which in this case is 365 days.

$\Sigma E_i F_i (RBE)_i n_i$ - effective energy for organ of reference = 0.0027 for ^{133}Xe and 0.090 for ^{135}Xe (4)

Referring back to equation 3 the adult MPC_w's for drinking are,

$$^{133}Xe_{MPC_w} = \frac{(1.3\times10^{-6})(10{,}000)(0.1)(0.151)}{(0.95)(1-e^{-(0.143)(365)})(0.0027)} = 7.7\times10^{-2}\mu Ci/ml \qquad 12.$$

$$^{135}Xe_{MPC_w} = \frac{(1.3\times10^{-6})(10{,}000)(0.1)(1.82)}{(0.95)(1-e^{-(1.82)(365)})(0.090)} = 2.8\times10^{-2}\mu Ci/ml \qquad 13.$$

The MPC_w's calculated above are for the adult population and are not representative of MPC_w's for the general population. In order to calculate MPC_w's for the general population the age distribution of the population must be considered. However, it would be impractical to add this variable to the MPC_w calculational scheme. As such, and in keeping with the philosophy of 10 CFR 20, the adult MPC_w's are lowered by a factor of ten to arrive at general population MPC_w's. The MPC_w's for ^{133}Xe and ^{135}Xe are then:

$$^{133}Xe_{MPC_w} = 8 \times 10^{-3}\ \mu Ci/ml$$

$$^{135}Xe_{MPC_w} = 3 \times 10^{-3}\ \mu Ci/ml$$

IV. Conclusions

MPC_w's were calculated for ^{133}Xe and ^{135}Xe in water. The critical organ was the body fat. The MPC_w values found were lower than the solubility of Xenon in water. Further analysis has shown that drinking water is the critical dose pathway. Appendix A of this report reviews other dose pathways.

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References

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Appendix A

I. Introduction

In this appendix general population MPC_w's are calculated for dose pathways other than drinking for Xenon in water. These pathways are swimming and shine at the shoreline. Adult dose conversion factors are also calculated for these pathways as well as the drinking water pathway. General population MPC_w's and adult dose conversion factors were chosen to agree with 10 CFR 20 and ALAP philosophy respectively.

II. Swimming Pathway

The calculation of an MPC_w equal to 5000 mrem/year for the swimming pathway is based on the following assumptions:

1. The maximum individual swims 100 hours per year (1)
2. The critical organ is the whole body
3. Adult dose conversion factors (DCF) are (1):
   5.7×10^{-8} mrem/hr/pCi/l for ^{133}Xe
   4.5×10^{-7} mrem/hr/pCi/l for ^{135}Xe

The equation for calculating an MPC_w based on a dose conversion factor is,

$$MPC_w(\mu Ci/ml) = (5000\ mrem/year)(10^{-9}\mu Ci/ml/pCi/l) \Big/ (DCF)(t) \qquad 1.$$

Therefore the adult MPC_w's are,

$$^{133}Xe_{MPC_w} = (5000)(10^{-9}) \Big/ (5.7\times10^{-8})(100) = 0.88\ \mu Ci/ml \qquad 2.$$

$$^{135}Xe_{MPC_w} \quad (5000)(10^{-9}) \Big/ (4.5\times10^{-7})(100) = 0.11\ \mu Ci/ml \qquad 3.$$

and the general population MPC_w's are,

$$^{133}Xe_{MPC_w} = 0.1\ \mu Ci/ml \qquad 4.$$

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$$^{135}Xe_{MPC_w} = 0.01\ \mu Ci/ml \qquad 5.$$

III. Direct Radiation At The Shoreline

Xenon is a noble gas and will not absorb in the sediments; therefore the exposure is limited to the shine dose from the dissolved gas. The following

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assumptions are made,

1. The problem is defined as primary ionization above an infinite disc where buildup due to scatter and absorption cancel each other out
2. At a point above the center of the disc the dose is equal to the 2π air immersion dose minus a correction factor, F (2)
3. Then at a point above one edge of this infinite disc the dose is ½ the 2π immersion dose minus a correction factor, that is,

$$D_{shine} = \tfrac{1}{2}\,(2\pi \text{ immersion dose})(1-F) \qquad 6.$$

where,

$$F = e^{-\mu_o} - \mu_o[E\mu_o] \qquad 7.$$

and,

$$E\mu_o = \int_1^{\infty} \frac{e^{-\mu_o t}}{t}\, dt \qquad 8.$$

therefore by integration,

$$E\mu_o = \log t + \frac{\mu_o t}{1!} + \frac{\mu_o^2 t^2}{2\cdot 2!} + \frac{\mu_o^3 t^3}{3\cdot 3!} \cdots \frac{\mu_o^n t^n}{n\cdot n!} \qquad 9.$$

apply limits with,

μ_o (^{133}Xe) = 0.2 cm^2/g (3) 10.

and μ_o (^{135}Xe) = 0.12 cm^2/g (3) 11.

then,

$E\mu_o$ (^{133}Xe) = 0.19 12.

and $E\mu_o$ (^{135}Xe) = 0.12 13.

and from equation 7,

F (^{133}Xe) = $e^{-0.2}$ - 0.2(0.19) = 0.78 14.

and F (^{135}Xe) = $e^{-0.12}$ - 0.12(0.12) = 0.87 15.

Therefore from equation 6 and utilizing the 2π immersion DCF's in reference 1 the dose conversion factors are,

DCF(^{133}Xe)=½(2.8x10^{-8}mrem/hr/pCi/l)(0.22)=3.1x10^{-9}mrem/hr/pCi/l 16.

DCF(^{135}Xe)=½(2.2x10^{-7}mrem/hr/pCi/l)(0.13)=1.4x10^{-8}mrem/hr/pCi/l 17.

And the adult MPC_w's for 5000 mrem/year are, in a fashion analagous to equation 1,

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$$^{133}Xe_{MPC_w} = \frac{(5000)(10^{-9})}{(3.1x10^{-9})(365)(24)} = 0.18 \mu Ci/ml \qquad 18.$$

$$^{135}Xe_{MPC_w} = \frac{(5000)(10^{-9})}{(1.4x10^{-8})(365)(24)} = 4.1x10^{-2} \mu Ci/ml \qquad 19.$$

And the general population MPC_w's are,

$$^{133}Xe_{MPC_w} = 0.02\ \mu Ci/ml \qquad 20.$$

$$^{135}Xe_{MPC_w} = 4 \times 10^{-3}\ \mu Ci/ml \qquad 21.$$

These MPC_w's are overly conservative in that they assume an individual would stand at the shoreline all year, which is unrealistic. The dose rate drops off very rapidly with distance from the shoreline.

IV. Determination of Dose Conversion Factors (DCF's)

A. Drinking Water Pathway

The DCF's are determined by rearranging equation 1 to,

$$DCF = \frac{(5000\ mrem/year)(10^{-9}\ \mu Ci/ml/pCi/l)}{(MPC_w\ \mu Ci/ml)(hours/year)} \qquad 22.$$

and substituting the appropriate values. The DCF's are,

$$^{133}Xe_{DCF} = \frac{(5000)(10^{-9})}{(7.7x10^{-2})(365)(24)} = 7.4x10^{-9} mrem/hr/pCi/l \qquad 23.$$

$$^{135}Xe_{DCF} = \frac{(5000)(10^{-9})}{(2.8x10^{-2})(365)(24)} = 2.0x10^{-8} mrem/hr/pCi/l \qquad 24.$$

B. Swimming Pathway

The DCF's are given in reference 1. They are, based on whole body dose,

$$^{133}Xe_{DCF} = 5.7 \times 10^{-8}\ mrem/hr/pCi/l \qquad 25.$$

$$^{135}Xe_{DCF} = 4.5 \times 10^{-7}\ mrem/hr/pCi/l \qquad 26.$$

C. Direct Radiation At The Shoreline

These values are as calculated in equations 16 and 17. They are,

$$^{133}Xe_{DCF} = 3.1 \times 10^{-9}\ mrem/hr/pCi/l \qquad 27.$$

$$^{135}Xe_{DCF} = 1.4 \times 10^{-8}\ mrem/hr/pCi/l \qquad 28.$$

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V. Summary

	General Population MPC_w Values based on 5000 mrem/year (μCi/ml)			Solubility in Water at 10°C and 80 natm. Xe
	Drinking	Swimming	Shoreline	
^{133}Xe	8×10^{-3}	0.1	0.02	18
^{135}Xe	3×10^{-3}	0.01	4×10^{-3}	250

Adult Dose Conversion Factors mrem/hr/pCi/l

	Drinking	Swimming	Shoreline
^{133}Xe	7.4×10^{-9}	5.7×10^{-8}	3.1×10^{-9}
^{135}Xe	2.0×10^{-8}	4.5×10^{-7}	1.4×10^{-8}

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Appendix B

I. Introduction

In this appendix adult dose conversion factors specific to TMINS are calculated for the applicable pathways. Adult dose conversion factors were chosen to agree with the ALAP philosophy. These pathways include the maximum individual drinking, the closest realistic drinking individual supplied by a water company, Brunner Island, the individual swimming, and the individual on the shoreline. All values are in mrem/hr/pCi/l for the effluent concentration.

II. Drinking Pathway

The liquid outfall at TMINS is submerged and is diluted approximately 1.7×10^4 times. This dilution factor is based on a maximum pump flow of 30 gpm, a minimum blowdown flow of 5000 gpm and a river dilution factor of 100. Therefore the concentration of radio-Xenon in the river water (C_w) is

$$C_w = {}^{C_E}\big/_{1.7 \times 10^4}$$

where C_E is the concentration of radio-Xenon in the station effluent.

A. Maximum Individual

The maximum individual drinks 1200 ml of river water per day at the point of discharge. If credit is taken only for dilution and not for physical decay the TMINS site specific dose conversion factors are,

$${}^{133}Xe_{DCF} = \frac{(7.4\times10^{-9})\left(\frac{1200}{2200}\right)}{1.7\times10^4} = 2.4 \times 10^{-13}$$

$${}^{135}Xe_{DCF} = C_E\,\frac{(2.0\times10^{-8})\left(\frac{1200}{2200}\right)}{1.7\times10^4} = 6.4 \times 10^{-13}$$

B. Individuals That Work At Brunner Island

The individuals who work at Brunner Island drink 600 ml of water during their work day. The Brunner Island river intake is 4.2 miles below the TMINS outfall and as such the travel time is about 9 hours. For calculation of these dose conversion factors credit for radioactive decay equal to the travel time is taken. The dose conversion factors are,

$${}^{133}Xe_{DCF} = C_E\,\frac{(7.4\times10^{-9})\left(\frac{600}{2200}\right)e^{-(.131)\left(\frac{9}{24}\right)}}{1.7\times10^4} = 1.1 \times 10^{-13}$$

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$$^{135}Xe_{DCF} = C_E(2.0x10^{-8}) \frac{600}{2200} e^{-(1.82)(\frac{9}{24})} \Big/ 1.7x10^4 = 1.6 \times 10^{-13}$$

II. Swimming Pathway

$$^{133}Xe_{DCF} = (5.7x10^{-8}) \Big/ 1.7x10^4 = 3.4 \times 10^{-12}$$

$$^{135}Xe_{DCF} = (4.5x10^{-7}) \Big/ 1.7x10^4 = 2.6 \times 10^{-11}$$

III. Direct Radiation At The Shoreline

$$^{133}Xe_{DCF} = (3.1x10^{-9}) \Big/ 1.7x10^4 = 1.8 \times 10^{-13}$$

$$^{135}Xe_{DCF} = (1.4x10^{-8}) \Big/ 1.7x10^4 = 8.2 \times 10^{-13}$$

IV. Sample Problem

If the effluent at TMINS contained 10^{-2} μCi/ml (10^7 pCi/ l) each of ^{133}Xe and ^{135}Xe the resultant doses to the adult population are as in the table below.

	Max Ind Drinking	Brunner Is Drinking	Swimming 100 hours/yr	Shoreline all year	
^{133}Xe	$2.1x10^{-2}$	$9.6x10^{-3}$	$3.4x10^{-3}$	$1.6x10^{-2}$	mrem/yr
^{135}Xe	$5.6x10^{-2}$	$1.4x10^{-2}$	$2.6x10^{-2}$	$7.2x10^{-2}$	mrem/yr

Total = .218 mrem/yr

$7.7x10^{-2}$ $2.4x10^{-2}$ $2.9x10^{-2}$ $8.8x10^{-2}$

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