Public Comment #28

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**BEFORE THE ILLINOIS POLLUTION CONTROL BOARD**

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| REVISIONS TO RADIUM WATER<br>QUALITY STANDARDS: PROPOSED<br>NEW 35 ILL. ADM. CODE 302.307<br>AND AMENDMENTS TO 35 ILL. ADM.<br>CODE 302.207 AND 302.525 | )<br>)<br>)<br>)<br>)<br>) | R2004-021<br>Rulemaking - Water |

## NOTICE OF FILING

PLEASE TAKE NOTICE that the Environmental Law & Policy Center and Sierra Club have filed the attached POST-HEARING COMMENTS OF THE SIERRA CLUB AND ENVIRONMENTAL LAW AND POLICY CENTER.

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DATED: December 8, 2004

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## BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

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REVISIONS TO RADIUM WATER )
QUALITY STANDARDS: PROPOSED )
NEW 35 ILL. ADM. CODE 302.307 ) R04-21
AND AMENDMENTS TO 35 ILL. ADM. ) Rulemaking - Water
CODE 302.207 AND 302.525 )
)

## POST- HEARING COMMENTS OF THE SIERRA CLUB AND THE ENVIRONMENTAL LAW AND POLICY CENTER

The Environmental Law and Policy Center and the Sierra Club do not envy the Board's position in trying to decide what to do in this proceeding. Despite four hearings, the information available to the Board is not adequate to make a confident scientific judgment as to the proper general use water quality standard to adopt for radium.

We believe that it is clear that the Board cannot properly adopt the Agency proposal as submitted insofar as it removes water quality standards for general use waters. Although the relevant scientific evidence in the record is much less than one might wish, the record does establish that a water quality standard is needed to protect aquatic life and riparian wildlife and that the numeric standard to be adopted to protect riparian wildlife probably must be more stringent than that necessary to protect drinking water. Water quality standards must protect the "most sensitive use" of the water body (40 CFR 131.11), which in this case appears to be riparian mammals.

### I. Introduction

The Board might well decide that it simply does not have the information necessary to change the standard at this time. Assuming the Board believes it should go forward to adopt a standard on the basis of the current record, we present below what we believe is the general use standard best supported by the record in this proceeding. Before presenting this standard, however, it may be helpful to discuss several principles applicable to the decision.

First, because the proposal is for a statewide water quality standard that is to be applicable to all general use waters of the state, the number adopted must protect the most sensitive use present in general use waters. See generally, *In the Matter of: Petition of Illinois Power Company (Vermilion Power Station) for Adjusted Standards from 35 Ill. Adm. Code 302.208 (e)*, AS No. 92-7, 1993 Ill, Env. Lexis 1018 (1993). Obviously, this means that the standard adopted will be overprotective for many uses. For example, it may well be that the Board must adopt a standard to protect riparian animals that is more stringent than would be necessary to protect drinking water for humans. This does not mean that the Clean Water Act prefers river otters over humans, but that river otters that live in and near a water body, and get almost all their food and drink from that water body, will have a much greater exposure to contaminants in the water than someone who just drinks water from the water body. The standard we suggest below is far less stringent than a standard would be that was as protective of river otters as the drinking water standard is of humans. See R04-21 Transcript of Proceedings Oct. 22, 2004 at 234-38.

It is very common in the Illinois water quality standards for a standard to be set that protects aquatic life or some other use that is more stringent than the standard necessary to protect drinking water. A comparison of 35 Ill. Adm. Code Section 302 Subparts B and C discloses that for many chemicals there is no standard for drinking water and food processing water supply that is more stringent than the standards designed to protect aquatic life. Water quality standards must protect the most sensitive use, and often the most sensitive use is a fish or animal population that has a far greater exposure to the toxin in question than humans.

Further, because the general use standards apply to almost all the water bodies of the state, the standards set may be overprotective of aquatic life in waters that do not contain the most sensitive species. For example, if protection of otters is the most sensitive use, the standards may be stronger than necessary for waters that cannot possibly serve as river otter habitat. This problem can possibly be addressed in later site specific proceedings but standards applicable to all general use waters throughout the state must protect all the life dependent on those waters throughout the state.

## II. Radium Rulemaking Recommendations

The Environmental Law and Policy Center and the Sierra Club recommend that the Board:

1) Maintain General Use and Lake Michigan basin water quality standards for radium
2) Set such standards at a level of 3.7 pCi/L combined radium 226 and radium 228
3) Ensure that particles containing high levels of radium are not discharged into Illinois waterways

The bases for our recommendations are detailed below.

### A. The Board Should Maintain General Use and Lake Michigan Basin Water Quality Standards for Radium Protective of Riparian Organisms

1. The scientific community has expressed concern with the effects of radium on non-human life forms living in and/or near bodies of water through years of detailed study, resulting in numerous peer-reviewed publications. See Exhibit 1: Literature Review of Radium in Water, Sediments & Biota, especially Clulow (We received this document on Nov. 30, 2004 from Doug Leeper, Senior Environmental Scientist, Southwest Florida Water Management District.)

2. Under the federal Department of Energy Organization Act, the U.S. Department of Energy has the responsibility to "ensure the incorporation of national environmental protection goals in the formulation of energy programs, and advance the goal of restoring, protection [sic],

and enhancing environmental quality." See Exhibit 2: DOE 5400.1, citing 42 USC 7131. In this role, DOE has recognized the threat that radiation poses to non-humans by promulgating a radiation dose limit of 1 rad/d for the protection of aquatic animals and 0.1 rad/d for the protection of terrestrial animals (based on mammals' higher sensitivity to radiation). Exhibit 3: DOE Order 5400.5. DOE adopted and implemented these radiation dose standards consistent with the recommendations of the International Commission on Radiological Protection, an international body utilizing the latest in scientific understanding of health risks and dosimetry. Id.

3. DOE has been interested in assessing detrimental effects to aquatic biota from radionuclides in the environment, using the dose limits above, since at least 1993. See Exhibit 4: B.G. Blaylock, "Methodology for Estimating Radiation Dose Rates to Freshwater Biota Exposed to Radionuclides in the Environment," (1993). The more recent DOE Technical Standard, "A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota" (DOE-STD-1153-2002) (PCB R04-21, Exhibit 15) hereafter "DOE Technical Standard", sets forth a method for evaluating actual or potential doses to biota such that they can be compared to the dose limit described above. This method demonstrates a consensus among radiation scientists on the need to protect life forms other than humans from radiation from radium (and other radionuclides).

4. The DOE Technical Standard indicates that any Illinois general use and Lake Michigan basin water quality standards for radium should be designed to protect riparian organisms such as raccoons and river otters. These are the organisms in freshwater aquatic systems found to be most sensitive to radiation from radium sources (Table 6.2, page M1-38 in DOE Technical Standard). Thus the DOE Technical Standard utilizes 0.1 rad/day, the dose rate

limit for mammals (see above), to derive Biota Concentration Guides (BCG) for both radium 226 and radium 228 in both sediment and water.

There was testimony in these proceedings that an organism like the manatee would be a better candidate to use with the General Screening Phase of the graded approach of the DOE Technical Standard than a raccoon. (See Transcript of Proceedings Oct. 21-22, 2004 at 296). While the manatee certainly satisfies many of the assumptions used for the General Screen for riparian animals (dose rate limit of 0.1 rad/d, "semi-infinite" exposure to water and sediment), the DOE Technical Standard clearly includes such common Illinois inhabitants such as raccoons and river otters as riparian organisms to be protected by recommendation. This is shown by the description of riparian organisms given in various places in the document:

- Definition of riparian organisms (DOE Technical Standard, p. xlviii) - **Riparian Organisms** are those organisms related to, living, or located on the bank of a natural watercourse (as a river) or sometimes of a lake or a tidewater.
- **Figure 2.3** Exposure Pathways for Riparian Animals (DOE Technical Standard, p. M1-13) depicting a raccoon.
- **Table 7.6** Riparian animal kinetic/allometric relationship parameter values default for raccoon or river otter (DOE Technical Standard, p. M1-64)
- **Table 2.2** Examples of Representative Organisms That Could Serve as Indicators of Radiological Impact (DOE Technical Standard, p. M2-16 & 17) listing beaver, raccoon, alligator, mink, muskrat, and great basin spadefoot toad.

River otters clearly exist in Illinois, and currently are listed on the state's threatened species list. Otters feed primarily on fish, mussels, and other aquatic biota. See Exhibit 5: IDNR, "Illinois Endangered and Threatened Species, River Otter;" Exhibit 6: U.S. EPA, "Species Profile: River Otter," at 5; Exhibit 7: IDNR, "River Otter Species Account." Thus, as feeding habits largely determine an animal's exposure to radium due to bioconcentration of radium in lower aquatic prey species, otters may be expected to have a high exposure rate. According to an official of the Illinois Department of Natural Resources, river otters spend greater than 80% of their life in river water. (Telephone conversation with Joe Kath, IDNR biologist, Dec. 7, 2004)

The typical life span of an otter in the wild is 10 to 15 years, see Exhibit 6 at 6 and Exihibit 8: San Diego Zoo, "Animal Bytes: Otter," which is sufficiently long for an otter to be at risk for tumor induction, especially given the expected discharge of high radiation radium particulate from sewage treatment plants (see below).

These three points indicate that a degree of conservatism in selecting an appropriate water quality screening standard is warranted.

B. If the Board decides to change the standard based on the current record, it should set general use and Lake Michigan basin water quality standards for radium at a level no less stringent than 3.7 pCi/L combined radium 226 and radium 228

1. In the General Screening mode of the RAD-BCG calculator (an Excel spreadsheet semi-automated tool for implementing screening and analysis methods contained in the DOE Technical Standard), the maximum radionuclide concentration(s) in water which would not result in biota dose limits (BCGs) being exceeded can be calculated for any combination of 23 radionuclides present, including radium 226 and radium 228.

2. The General Screening mode is the conservative initial screening step in the DOE Technical Standard's three-step process for evaluating radiation doses to aquatic and terrestrial biota. As little data is available to inform this Rulemaking, the use of the general screening mode is appropriate. For example, the General Screening mode asks for radium levels in both water and sediment in order to assess whether BCGs are exceeded. In the absence of data on levels of radionuclides in either medium, the General Screen calculates a radium concentration for the other medium. As no data have been provided in this rulemaking on the levels of radium in sediment in Illinois, the use of the General Screen is appropriate.

In the absence of radiation from any other radionuclide source, a combined concentration of 3.7 pCi/L of radium 226 and radium 228 in the water column does not exceed the BCG for these two radionuclides. See Exhibit 9: RAD-BCG Calculations. In the absence of more Illinois specific information, we would recommend this as an appropriate water quality standard for Illinois general use waters and the Lake Michigan basin.

The DOE Technical Standard is the major piece of information on the impact of radiation on organisms found in aquatic systems, with specifics for radiation stemming from radium, which has been presented in these proceedings. While we would prefer to have more information, we believe that the DOE Technical Standard is a tool we should use in helping to guide us towards appropriate radium water quality standards for Illinois general use waters and the Lake Michigan basin. While the DOE Technical Standard states that 'The principal application of the graded approach is to demonstrate that routine DOE operations and activities are in compliance with the biota dose limits for protecting populations of plants and animals." (DOE Technical Standard, p. M1-17), it also indicates that the DOE graded approach can be used for Clean Water Act applications such as mixing zone assessments (DOE Technical Standard, p. M1-20).

There has been much discussion regarding the conservative assumptions of the standard, especially with regards to the initial General Screening Phase of the graded, three-step process in evaluating radiation doses to biota. We agree that the General Screen is generally designed to be a conservative first screen. The assumptions used in this General Screen are found in Table 2.2 (DOE Technical Standard, p. M1-12). In using the General Screen as a tool to aid us in this rulemaking, it is helpful to review a number of these assumptions.

| Assumption | Impact on Radium Water Quality Standard Rulemaking |
|---|---|
| External source of radiation exposure from water and sediment is uniform, continuous and "semi-infinite" | This is an appropriate assumption for a water quality standard.<br>For animals such as the river otter, this is an appropriate assumption. For some raccoons, which may spend part of their time outside of the riparian area, this assumption may be too conservative. A site-specific analysis that reduced the amount of time spent in the riparian area could be developed for organisms such as raccoons but as water quality standards must protect all Illinois fauna, this is not an inappropriate assumption in this situation.<br>At the same time, this assumption may be viewed as overly lenient, in that it only measures soluble radium and does not account for highly radioactive particulates that may be discharged by wastewater treatment plants. While we cannot now recommend writing a discharge standard for particulates, the threat from particulates may be recognized in the soluble water quality standard by taking a conservative approach overall. |
| Radiation exposure is determined by levels of up to 23 different radionuclides present in the water and sediment | A combined radium 226 and radium 228 standard based on the General Screen, without taking into account other sources of radioactivity, is not a completely conservative approach. |
| Populations of plants and animals are the primary intended use of the DOE Technical Standard. (Table 3.1, p. M1-17) | The DOE Technical Standard warns "Applying dose limits intended for the protection of populations to evaluations of individuals may require further consideration." (Table 3.1, p. M1-17). Therefore, the use of the General Screen to protect endangered and threatened species such as the river otter is a liberal use of the tool. |

### C. The Board and Illinois EPA should ensure that particles containing high levels of radium are not discharged into Illinois waterways

In the course of this rulemaking, concerns have been raised about the possibility of particles containing high levels of radium being discharged to Illinois waterways. Such particulates can contain thousands of times the radium level of the dose limit. It has been suggested that the wastewater treatment process facilitates creation of particulates and a portion of these particulates from wastewater treatment will be discharged back into the surface waters of Illinois.

Therefore, the water quality standard we recommend here (3.7 pCi/L for combined radium 226 and radium 228) for possible adoption is based on the assumption that the radium is present in a soluble form. We urge the Illinois EPA and the Board in permit writing, consideration of any site specific standards, and in future regulatory proceedings to take measures to ensure that highly radioactive particles are not released into Illinois waterways.

## III. Conclusion

There is no scientific basis for removing all the protections for aquatic and terrestrial life provided by the current general use radium water quality standard. If the Board believes the record is sufficient, modest changes to the standard, as suggested above, may be justifiable. In any case, in future proceedings the Illinois EPA and the Board should assure that radium is not released into the environment in any form that poses significant risks.

DATED: December 8, 2004

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Exhibit 1

# Literature Review
# Radium in Water, Sediments & Biota

**Doug Leeper**
**12 December. 2002**

**Al-Masri, M.S. and Blackburn, R.. 1999. Radon-222 and related activities in surface waters of the English Lake District. Applied Radiation and Isotopes 50: 1137-1143.**
Filtered water samples from 9 English lakes yielded $^{226}$Ra activities fm below detection level to 9.6 mBq/L (0.26 pCi/L).

**Barisic, D. , Lulic,S. and Miletic, P. 1992. Radium and uranium in phosphate fertilizers and their impact on the radioactivity of waters. Water Research 26: 607-611.**
Analysis of water, ground water, fertilizers used in Eastern Slavonia.
Typical fertilizer has Ra-226 activity of 4.5 dpm/g dry and higher levels of U-238.

**Bird, G. A., Schwartz, W. J, and Motycka, M. 1998. Fate of $^{60}$Co and $^{134}$Cs added to the hypolimnion of a Canadian Shield lake: accumulation in biota. Canadian Journal of Fisheries and Aquatic Sciences 55: 987-998.**
Added cobalt and cesium to Lake 226 in the ELA-measured fate in biota.
Mussel species: *Anodanta grandis grandis*
"Clams accumulated relatively high concentrations of the radionuclides (Figure 4) compared to the other biota. Initialy, more $^{60}$Co than $^{134}$Cs was accumulated by the clams, which may reflect the fact that $^{60}$Co is particle bound whereas $^{134}$Cs tends to remain in solution."
Cite Ophel and Fraser (1971) who reported high concentration of $^{60}$Co in *Elliptio* sp.
Moderate to high levels measured for mussels, periphyton, *Potamogeton*, *Hyalella*, odonates and tadpoles.

**Brenner, M., Peplow, A. J., and Schelske, C. L. 1994. Disequilibrium between $^{226}$Ra and supported 210Pb in a sediment core from a shallow Florida lake. Limnology and Oceanography 29: 1222-1227.**
Lake Rowell (north FL, Bradford County)
$^{226}$Ra in surface sediments = ~13 dpm/g dry based on grab sample.
Took core and found surface activity was 22.6 dpm/g dry (higher than other FL lakes surveyed at the time of the paper).
Total P and $^{226}$Ra correlated: r=0.97; suggests erosion or wash-in of "geologic material rich in both Ra and total P". Samples from creek inflow support this.

$^{226}$Ra in Mollusc Shells collected just downstream: *Corbicula* 1.3 dpm/g dry
Unionids 2.5
*Pomacea* 7.8

**Brenner, M., Whitmore, T. J., Cutis, J. H. and Schelske, C. L. 1995. Historical ecology of a hypereutrophic Florida lake. Lake and Reservoir Management 11: 255-271.**
Lake Hollingsworth data.

**Brenner, M., Whitmore, T. J., and Schelske, C. L. 1996. Paleolimnological evidence of historical trophic state conditions in hypereutrophic Lake Thonotosassa, Florida, USA.**
Lake Thonotosassa data.

**Brenner, M., Schelske, C. L. and Whitmore, T. J. 1997. Radium-226 stratigraphy in Florida lake sediments as an indicator of human disturbance. Verh. Internat. Verein. Limnol. 26: 809-813.**
Core data from 8 FL lakes showing Total P concentration and Ra-226 activity.
Correlation between P and Ra suggests common delivery mechanisms; increases upcore suggest anthropogenic cause. Could include construction of buildings and roads, plowing for agriculture and phosphate mining.
Note: Most cores show upcore increase in Ra and levels < 10 dpm/g dry; some show mid-core peaks (Thonotasassa ~30dpm/g dry).
Lake Rowell had surface Ra activity of ~23 dpm/g dry (~10 pCi/g).

**Brenner, M., Smoak, J. M., Allen, M. S., Schelske, C. L., and Leeper, D. A. 2000. Biological accumulation of $^{226}$Ra in groundwater-augmented Florida lake. Limnology and Oceanography 45: 710-715.**

*1999 samples*

| | | | | | | |
|---|---|---|---|---|---|---|
| $^{226}$Ra | Sediment | ~27 | dpm/g dry | ~12 | pCi/g dry | |
| | (sediment value from Brenner and Whitmore 1999) | | | | | |
| $^{226}$Ra | Well (mean of 4 values) | 6.2 | dpm/L | 2.8 | pCi/L | |
| | Lake (mean of 3 values) | 3.4 | | 1.5 | pCi/L | (0.0015pCi/g) |
| | *Nitella* | | 12.0 dpm/g dry | 5.4 | pCi/g dry | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Pomacea* | Shell | | 10.2 | | | 4.6 | | |
| *Planorbella* | | Shell | | 3.9 | | | 1.8 | |
| *Planorbella* | | Tissue | | 1.8 | | | 0.8 | |
| Mussel | Shell | | 38 | | | 17 | | |
| **Mussel** | **Tissue** | **356** | | | | **160** | | |

(mussel values are mean of 4 separate samples)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| FL Gar | Bone | | 3.2 | * | | 1.4 | * | |
| | | Fillet | | nd | | | nd | |
| Bluegill | Bone | | 6.5 | * | | 2.9 | * | |
| | | | | nd | | | nd | |
| Bass | | Bone | | 2.1 | * | | 1.0 | * |
| | | Fillet | | nd | | | nd | |
| **Lake Chub.** | | **Bone** | | **26.6** | * | | **12.0** | * |
| | | **Fillet** | | **0.6** | | | **0.3** | |
| Redear | Bone | | 7.3 | * | | 3.3 | * | |
| | | Fillet | | nd | | | nd | |
| Brown | Bone | | 4.0 | * | | 1.8 | * | |
| Bullhead | Fillet | | nd | | | nd | | |

nd = not detectable
* = fish bone data expressed as activity/g ash

Concentration factors (CF, based on activity in lake water = 0.0015 pCi/g):
Mussel shell (17pCi/g dry) CF= 11,333 $10^4$
Mussel tissue (160 pCi/g dry) 106,667 $10^5$
Mussel tissue (~16 pCi/g wet) 10,667 $10^4$

**Brunskill, G. J. and Wilkinson, P. 1987. Annual supply of $^{238}$U, $^{230}$Th, $^{226Ra}$, 210Pb, $^{210}$Po, and $^{232}$Th to Lake 239 (Experimental Lakes Area, Ontario) from terrestrial and atmospheric sources. Canadian Journal of Fisheries and Aquatic Sciences 44 (Supplement No. 1): 215-230.**
Some information on movement of dissolved radium.

**Burnett, W. C., Cowart, J. B., and Chin, P. A. 1987. Polonium in the surficial aquifer of west central Florida. Pages 251-269, in Graves, B. (ed.), Radon, radium and other radioactivity in ground water. Lewis Publishers, Inc., Chelsea, Michigan.**
Relatively high polonium-210 levels in shallow wells sampled in central Florida.

**Byrne, M., and Besk, P.A. 2000. Elemental composition of mantle tissue granules in *Hyridella depressa* (Unionidae) from the Hawksbury-Nepean River system, Australia: inferences from catchment chemistry. Marine and Freshwater Research 51: 183-192.**
Used x-ray microanalysis to determine elemental composition of CaP granules in mussel mantle tissue. Includes discussion of the possible role of the granules.
**Cherry, R. D. 1964. Alpha-radioactivity of plankton. Nature 203: 139-143.**
Total alpha-activity in marine plankton from samples in Indian? Ocean.

| | | | | |
|---|---|---|---|---|
| Zooplankton | Range: | 1.8-12 | pCi/g dry | |
| | | | | 4.0-26.6 dpm/g dry |
| Phytoplankton | Range: | 3.4-95.5 | pCi/g dry | |
| | | | | 7.5-212 dpm/g dry |

**Clifford, D. A. 1990. Removal of radium from drinking water. Pages 225-247, in Cothern, C. R., and Rebers, P. A. (eds.), Radon, radium and uranium in drinking water. Lewis Publishers, Inc., Chelsea, Michigan.**
Not much

**Clulow, F. V., Dave, N. K., Lim, T. P., and Cloutier, N. R. 1988. Uptake of $^{226}$Ra by established vegetation and black cutworm larvae, *Agrotis ipsilon* (Class Insecta: Order Lepidoptera), on U mill tailings at Elliot Lake, Canada. Health Physics 55: 31-35.**
Cutworm Ra-226 levels (~7 dpm/g dry) considered to be too low to be a hazard to herring gulls that may feed on the insects.

**Clulow, F. V., and Pyle, G. G. 1997. Radium-226 equilibrium between water and lake herring, *Coregonus artedii*, tissues attained within fish lifetime: confirmation in this species of one assumption in the simple linear concentration factor model. Environmental Pollution 96: 75-78.**
Test of achievement of equilibrium (an assumption of a simple concentration factor model) between environmental compartments and body tissues of lake herring from Quirke Lake.

| | | | |
|---|---|---|---|
| Muscle | ~0.07 | pCi/g dry max | |
| Bone | ~0.5 | | max (3 other samples ~<0.24 pCi/g dry) |

**Clulow, F. V., Clouteir, N. R., Dave, N. K., and Lim, T. P. 1996. Radium-226 concentrations in faeces of snowhoe hares, Lepus americanus, established near uranium mine tailings. Journal of Environmental Radioactivity 3: 305-314.**
Terrestrial study.

**Clulow, F. V., Dave, N. K., Lim, T. P., and Avadhanula, R. 1998. Radium-226 in water, sediments, and fish from lakes near the city of Elliot Lake, Ontario, Canada. Environmental Pollution 99: 13-28.**
Measured Ra-226 in water, lake sediments, fish bone, and fish muscle from 5 study and 2 control lakes near U mining and milling operations and control area in Ontario, Canada.

| | | | | |
|---|---|---|---|---|
| Water (dissolved) | Control | 0.2 | pCi/L | max |
| | Study | 2.0 | | max |
| Sediments | Control | 9.1 | pCi/g dry | max |
| | Study | 42.8 | | max |
| Fish Bone | Control | 0.4 | pCi/g dry | max |
| | Study | 2.0 | | max |
| Fish Muscle | Control | 0.2 | pCi/g dry | max |
| | Study | 0.1 | | max |

**Clulow, F.V., Dave, N. K., Lim, T. P., and Avadhanula, R. 1998. Radionuclides (lead-210, polonium-210, thorium-230, and -233) and thorium and uranium in water, sediments, and fish from lakes near the city of Elliot Lake, Ontario, Canada. Environmental Pollution 99: 199-213.**
Companion study to Clulow et al. (1989) paper on Ra-226 levels.

**Clulow, F. V., Dave, N. K., Lim, T. P., and Cloutier, N. R. Date Unkown. U- and Th-series radionuclides in snowshoe hare (*Lepus americanus*) taken near U mill tailings close to Elliot Lake, Ontario, Canada. Environmental Pollution X: 23-281.**
Analyzed bone tissue samples. Radionuclide activity at levels thought to be below effects threshold for mammals.
GET HIS PAPER ON BEAVE RA LEVELS

**Coats, B. 2002. Lake warning: please don't eat the mussels. Published December 13, 2002 in the St. Petersburg Times, St. Petesburg, Florida.**
Popular article on lake radium data for P886 study. Includes a recommendation from me that mussels should not be consumed.

**DeBortoli, M. and Gaglione, P. 1972. Radium-226 in environmental materials and foods. Health Physics 22: 43-48.**
Data for 4 Italian lakes, including Lake Maggoire

| | | | |
|---|---|---|---|
| $^{226}$Ra | Water | 0.16 | pCi/L |
| | Fish (*Perca*) | 0.001-0.003 | pCi/g fresh |

**Ehlers, S. 1972. Fresh water clams. Florida Wildlife 26: 14-19.**
Popular article on potential food value of *Corbicula manilensis*. Includes recipes.

**Emerson, S., Broeker, W., and Schindler, D. W. 1973. Gas-exchange rates in a small lake as determined by the radon method. Journal of the Fisheries Research Board of Canada 30: 1475-1484.**
Studied gas exchange of Lake 227 in the ELA by adding sufficient radium-226 (9.7mCi) to bring the level to ~200 dpm/L (~90 pCi/L).
One month after addition, levels were low - radium taken up in littoral zone
See Emerson and Hesslein (1973) for report on fate of the radium.

**Emerson, S. and Hesslein, R. 1973. Distribution and uptake of artificially introduced radium-226 in a small lake. Journal of the Fisheries Research Board of Canada 30: 1485-1490.**
Radium-226 added to Lake 227 in ELA in 1970 to study gas exchange (see Emerson *et al.* 1973). Expected radium to stay in solution, but it did not - the study was undertaken to evaluate fate of the radium.
Results: Ra taken up by epilithic community (which is mostly diatoms) in the littoral zone. Confirmed epithilic uptake of radium at natural levels in two other lakes (Lakes 239 and 240). So, the deposition seems to be associated with the living biofilm, rather than physical/sediment process, but not enough data to fully confirm.
Photosynthesis experiment showed no correlation between photosynthesis and radium uptake, so the accumulation may be adsorption, rather than uptake.
They note that fall turnover may redistribute radium from littoral zone to deeper areas.

**Environmental Science and Engineering, Inc. 1985. Ecological considerations of reclaimed lakes in central Florida's phosphate region, Vols. I and II. Publications Number 03-018-029 and 03-018-030 of the Florida Institute of Phosphate Research, Bartow, Florida.**
Data on radium in water, sediments and biota of reclaimed phosphate mine pits and a few "natural" Polk County lakes (Arietta, Hollingsworth, Hunter) and a reservoir (Lake Manatee) in Manatee County.

Ra-226 in reclaimed vs. natural lakes not different. Note that water values are lower than at Round Lake where Ra-226 ~ 2.9 pCi/L.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Water | Reclaimed Lakes | 0.38 | pCi/L | mean | 0.6 | pCi/L | max |
| | Natural Lakes | 0.35 | pCi/L | mean | 0.5 | pCi/L | max |

Ra-226 higher in sediments of reclaimed vs. natural lakes (based on geometric means)
Means listed here are arithmetic means.

| | | | | | |
|---|---|---|---|---|---|
| Sediments | Reclaimed | 48.0 | dpm/g dry | (21.6 pCi/g dry) | mean |
| | Natural | 6.0 | dpm/g dry | (2.7 pCi/g dry) | mean |
| | Agrico#2 | 100.5 | dpm/g dry | max for all sites | |

Zooplankton analyzed as pooled samples for each lake; assemblages were similar among lakes (according to authors) and dominated by rotifers and copepod nauplii. Ra-226 significantly higher in zoops from reclaimed lakes.

| | | | | | | |
|---|---|---|---|---|---|---|
| Zooplankton | Reclaimed | 113.2 | dpm/g dry | 51.0 | pCi/g dry | mean |
| | Natural | 72.8 | dpm/g dry | 32.8 | pCi/g dry | mean |

Total Bethos (excluding Mollusca) did not differ between lake types.

| | | | | | | |
|---|---|---|---|---|---|---|
| Benthos | Reclaimed | 9.6 | dpm/g dry | 4.3 | pCi/g dry | mean |
| | Natural | 7.5 | dpm/g dry | 3.4 | pCi/gdry | mean |

*Corbicula* was the dominant mollusk. Mollusc flesh typically had higher activity than shell.

| | | | | | | |
|---|---|---|---|---|---|---|
| Mollusca | Medard | Shell | 0.70 | dpm/g dry | 0.3 | pCi/g dry |
| | | Flesh | 9.8 | dpm/g dry | 4.4 | pCi/g dry |
| | Arietta | Shell | 3.1 | dpm/g dry | 1.4 | pCi/g dry |
| | | Flesh | **47.5** | dpm/g dry | 21.4 | pCi/g dry |
| | Hunter | Shell | 4.2 | dpm/g dry | 1.9 | pCi/g dry |
| | | Flesh | 2.4 | dpm/g dry | 1.1 | pCi/g dry |
| | Manatee | Shell | 0.4 | dpm/g dry | 0.2 | pCi/g dry |
| | | Flesh | 4.7 | dpm/g dry | 2.1 | pCi/g dry |

Smaller fish (*e.g.,* golden shiner, threadfin shad, mosquitofish) processed whole for Ra-226; larger fish separated into bone and flesh – whole activity for larger fish also determine as weighted average of bone and flesh values. Forage fish had higher activites – therefore no evidence for biomagnification.

Ra-226 detected in numerous flesh samples (unlike P886 data with no detects).

| | | | | | | |
|---|---|---|---|---|---|---|
| Fish Flesh | Max Value<br>(Agrico#1) | Fl Gar | 2.9 | dpm/g dry | 1.3 | pCi/g dry |

Ra-226 detected in most fish bone samples. "In general, Ra-226 was higher in bone than in fish flesh."

| | | | | | | |
|---|---|---|---|---|---|---|
| Fish Bone | Max Value | Chubs | 29.4 | dpm/g dry | 13.3 | pCi/g dry |

(Arietta, which had relatively high values for many species).

Plants as a group did not differ in Ra-226 activity between reclaimed vs. natural lakes.

*Typha* belowground tissue activity was higher in reclaimed systems, but above ground was not. Ra-226 activity typically above 1 pCi/g dry for above ground tissue. Some taxa in some lakes exceeded 10pCi/g dry (*Lemna minor, Hydilla veticillata, Hydrocotyle umbellate, Azolla, Eleocharis vivipara, & Najas quadalupensis*)

| | | | | | |
|---|---|---|---|---|---|
| Max Value | *Hydrilla* Agrico#6 | 45.1 | dpm/g dry | 20.3 | pCi/g dry |
| Max Value | *Lemna* | 30.0 | dpm/g dry | 13.5 | pCi/gdry |
| Other | *Hydrocotyle* | 31.1 | dpm/g dry | 14.0 | pCi/g dry |
| Taxa | *Azolla* | 43.1 | dpm/g dry | 19.4 | pCi/g dry |
| | *Eleocharis* | 41.5 | dpm/g dry | 18.7 | pCi/g dry |
| | *Najas guadalup..* | 26.6 | dpm/g dry | 12.0 | pCi/g dry |

**Fanning, K. A., Breland, J. A., and Byrne, R. H. 1982. Radium-226 and radon-222 in the coastal waters of west Florida: high concentrations and atmospheric degassing. Science 215: 667-670.**
Data obtained from cruises and sampling trips around Tampa Bay and selected rivers in 1980 and 1981.

| | | | |
|---|---|---|---|
| $^{226}$Ra | Tampa Bay surface waters - 1981 | 0.3-1.45 | pCi/L |
| | Peace River, 25 km upstream from mouth | | 0.45 |
| | Peace River, 35 km upstream from mouth | | 0.4 |
| | Alafia River, 8 km upstream from mouth<br>(Sam Upchurch, cited as pers. comm.) | 1.7 | |
| | Alafia River, at mouth, near fertilizer plant<br>(Sam Upchurch, cited as pers. comm.) | | 2.5 |
| | Little Manatee, 10 km upstream from mouth | 0.8 | |

*Elevated* levels attributed to the geology of west central FL (phosphate deposits). Also some input from geothermal spring southwest of Ft. Myers.

**FIPR (Florida Institute of Phosphate Research). 1986. Radiation and your environment: a guide to low-level radiation for citizens of Florida. Publication number 05-000-036 of the Florida Institute of Phosphate Research, Bartow, Florida.**
General discussion of radiation sources and risks.

**Fisher, N. S., Teyssie, J. L., Krishnaswami, S. and Maskaran, M. 1987. Accumulation of Th, Pb, U, and Ra in marine phytoplankton and its geochemical significance. Limnology and Oceanography 32: 131-142.**
Lab study of radionuclide uptake. Based on the measured accumulation, they speculate that sinking plankton could account for "most of the natural series radionuclides sedimenting out of oceanic surface waters".

**Florida Sportsman On-Line. 2000. Curbing your mussel intake. Florida Sportsman Casts, October 2, 2000. Web site: www.floridasporsman.com.**
Popular article includes recommendation that people not eat mussels regularly.

**Frank, B.J, and Irwin, G.A. 1980. Chemical, physical, an radiological quality of selected public water supplies in Florida, January-May 1979. Water Resources Investigations 80-13. United States Geological Survey, Tallahassee, Florida.**
Sampled 131 surface and groundwater public water supplies in 1979.

| | | |
|---|---|---|
| Gross-alpha | <0.7 – 8.2pCi/L | Surface supplies |
| | <3.7 – 19.0 | Ground water supplies |

**Harada, K., Burnett, W. C., LaRock, P. A., and Cowart, J. B. 1989. Polonium in Florida groundwater and its possible relation to the sulfur cycle and bacteria. Chimica et Cosmochimica Acta 53: 143-150.**
$^{226}$Ra 0.5 pCi/L Water from a single 5.5m deep well in SE Hillsborough Co. Well has high Polonium and Radon levels.

**Hazardous Substance and Waste Management Research, Inc. 2000. Human health risk assessment and preliminary ecologic evaluation regarding potential exposure to radium-226 in several central Florida lakes. Prepared for the Southwest Florida Water Management District, Brooksville, Florida.**
Estimates of cancer morbidity and mortality risks associated with Ra-226 activities in Round Lake water, the groundwater used to augment the lake, sediments from 2 paleolimnological cores, and biota (including samples reported in Brenner *et al.* 2000 and additional mussel samples).
Also includes risk assessments for Ra-226 activities in mussels from Lakes Armistead, Jackson, Halfmoon, Saddleback, Panasoffkee,

**Havlik, B. Radium in aquatic food chains: radium uptake by freshwater algae. Radiation Research 46: 490-505.**
Lab uptake experiment. Some species absorb the radium, others adsorb it.
Discussion section begins with review of old reports on radium accumulation. One study cites accumulation in tubificids.

**Heit, M., Klusek, C. S., and Miller, K. M. 1980. Trace element, radionuclide, and polynuclear aromatic hydrocarbon concentrations in Unionidae mussels from northern Lake George. Environmental Science and Technology 14: 465-468.**
Mussels (*Lampsilus radiata, Ellliptio complanatus* and *Anodonata grandis*) from Lake George, NY shown to concentrate some metals and radionuclides, and possibly some polynuclear aromatic hydrocarbons in soft tissues. No activity or concentrations determined for shell material.
*Elliptio complanatus* (n=32) was the only taxon examined for radionuclide concentration: It accumulated radionuclides from weapons-tests, but natural nuclides of the uranium-238 series (thorium-234, Pa-234m, radium-226, lead-214 and bismuth-214), the thorium-232 series (Ac-238, lead-212, Tl-208) and potassium-40 ***were not*** detected in mussel soft tissue.
Suggest that the unionids may be used for biomonitoring for metals and radionuclides.

**Hesslein, R. H., Broecker, W. S., and Schindler, D. W. 1980. Fates of metal radiotracers added to a whole lake: sediment-water interactions. Canadian Journal of Fisheries and Aquatic Sciences 37: 378-386.**
Added several radiotracers (but not radium) to Lake 224 at the ELA, Ontario, Canda.
Isotopes that adsorb to particulate matter were more readily transported to sediments than those in dissolved form.

**Hesslein, R. H., and Slavicek, E. 1984. Geochemical pathways and biological uptake of radium in small Canadian Shield lakes. Canadian Journal of Fisheries and Aquatic Sciences 41: 459-468.**
Added Ra-226 to four Canadian lakes in the 1970s.
Water in 1981 (range) 0.2 - 0.4 pCi/L (an order of magnitude higher than values for 3 control lakes)
Plants: *Lobelia, Ericoaulon* and *Potamogeton* rapidly took up Ra when spiked Peaked within 20 days, stabilized in 3-4 mo.
Range: 0.3 1.4 pCi/g wet in L224

*Lobelia* and *Eriocaulon* averaged ~1pCi/g wet in L226.

Crayfish: peaked at ~10 pCi/g wet
(Assuming a 10% wet/dry fudge factor peak would be ~100 pCi/g dry)
(Range: ~7 to 115 pCi/g dry based on fig. 3 & my fudge factor).

Fish: Ra accumulated by lake trout, white sucker, lake whitefish, pearl dace, northern redbelly dace, and fathead minnow.

Max value ~0.03 pCi/g wet (whole fish?).

3-Step Process for Ra Fate & Transport

1. Rapid deposition in sediments.
2. Slower decrease associated with water renewal.
3. Long-term burial by sediment accumulation.

On p. 466 talks about the use of observed (Ca/Ra) ratios: "The fundamental principle in this approach is that radium (or strontium) follows the same biological pathway as calcium but is favored or discriminated against to a greater or lessor extent in different processes or organisms. The selection for or against radium as compared with calcium is expected to be greater than for strontium because of the larger differences in atomic weight, radii, etc."

Data suggests that "Radium is favored over calcium in macrophytes and crayfish but is discriminated against strongly in fish". Fast-growing fish or fish with lots of calcium in diet could be more influenced by Ra levels.

Low Ca and long water residence time in Canadian Shield lakes makes them susceptible to radium uptake from U mining in area.

**Hesslein, R. H. 1987. Whole-lake metal radiotracer movement in fertilized lake basins. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 1): 74-82.**

Isotopes of Se, Hg, St, Cs, Fe, Zn and Co added to the two separated basins of Lake 226 in the ELA, Ontario (this lake is Schindler's eutrophication study lake).

**Holtzman, R. B. 1967. Concentrations of the naturally occuring radionuclides $^{226}$Ra, $^{210}$Pb and $^{210}$Po in aquatic fauna. Pages 535-546, in Helson, D. J., and Evans, F. C. (eds.), Proceedings of the Second National Symposium on Radioecology, Ann Arbor, Michigan.**

Samples from fish store, biological supply houses, whale stomachs, *etc.*

| | | |
|---|---|---|
| $^{226}$Ra | 0.05 | pCi/g ash Ocean fish-bone |
| | 0.0016 | pCi/g wet Ocean fish-soft tissue |
| | 0.02 | pCi/g ash Great Lakes-pike bone |
| | 0.0002 | pCi/g wet Great Lakes-pike soft tissue |
| | 0.04 | pCi/g wet **Clams**-canned (from Japan) |
| | 0.003 | pCi/g wet *Calanus* sp. |

**Humphreys, C. L. 1987. Factors controlling uranium and radium isotopic distributions in groundwater of the west-central Florida phosphate district. Pages 171-189, in Radon, Radium and Other Radioactivity in Ground Water: Hydrogeologic Impact and Application to Indoor Airborne Contamination, Proceedings of the NWWA Conference, April 7-9, 1987, Somerset, New Jersey. Lewis Publishers, Inc., Chelsea, Michigan.**

Sampled 120 wells in central FL (SE Hillsborough, Polk, Hardee, DeSota, Manatee and Sarasota Couties). Samples collected from land-pebble phosphate region (both mined and unmined areas) and from adjacent unmineralized area (southwestern portion of study area) known to have high radium levels. Ra in unmineralized area considered to be secondary deposit of mobile radionuclides from mineralized area – also influenced by salt content

| | | | | |
|---|---|---|---|---|
| $^{226}$Ra | Mined Area | Surficial | 2.1 | pCi/L (average) |
| | | Secondary artesian | 3.5 | |
| | | Floridan | 2.1 | |
| | Unmined Area | Surficial | 3.5 | |
| | | Secondary artesian | 3.6 | |
| | | Floridan | 4.1 | |
| | Unmineralized Area | Surficial | 10.4 | |
| | | Secondary artesian | 7.8 | |
| | | Floridan | 5.8 | |

**International Atomic Energy Agency. 1992. Effects of ionizing radiation on plants and animals at levels implied by current radiation protection standards. Technical Reports Series No. 332. Vienna, Austria.**

Non-human effects associated with release of radionuclides to surface waters (p. 40), based on fish consumption at rate of 100 kg/annually, water consumption at rate of 2L/day, and external exposure from contaminated sediments with an occupancy rate of 2000 hours/annually.

**Irwin, G. A. and Hutchinson, C. B. 1976. Reconnaissance water sampling for radium-226 in central and northern Florida, December 1974 - March 1976. U. S. Geological Survey Water Resources Investigations 76-103. U. S. Geological Survey, Tallahassee, Florida.**

Analyzed 115 water samples (mostly ground water, some surface samples, principally from Peace River drainage) from Hillsborough, Polk, Manatee, Hardee, DeSoto and a few north FL counties. Sampling was limited to areas of active phosphate mining and areas of undisturbed phosphate deposits, so data may not be representative of areas without phosphate deposits.

11 of 13 Surface samples (exceptions - slime pit and a site in Little Charlie Creek) did not exceed the state standard (3pCi/l at the time of the report).

| | | |
|---|---|---|
| $^{226}$Ra | Peace River surface water (mean of 13 samples) | 0.12-1.5pCi/L |
| | Alafia River at Lithia | 0.06-0.53 |
| | Little Charlie Creek (Hardee Co.) | 3.6 |

Ground Water samples (filtered, unacidified) in Hills Co.

| | | | |
|---|---|---|---|
| $^{226}$Ra | 31 ft deep0.2 | pCi/L | SA (surficial aquifer) |
| | 17 | 4.5 | SA |
| | 11 | 1.5 | SA |
| | 22 | 0.2 | SA |
| | 22 | 0.29 | SA |
| | 17 | 0.2 | SA |
| | 826 | 0.06 | UF (upper Floridan) |
| | 160 | 0.24 | UF |
| | 22 | 0.32 | SA |
| | 23 | 0.2 | SA |
| | 60 | 1.6 | UF |
| | 22 | 0.94 | SA |

Ground Water samples (filtered, acidified) in Hills. Co.

| | | | |
|---|---|---|---|
| $^{226}$Ra | 160 ft | **20.0** | pCi/L |
| | 826 | 0.14 | |

**Jeffree, R. A. and Simpson, R. D. 1984. Radium-226 is accumulated in calcium granules in the tissues of the freshwater mussel, *Velesunio angasi*: support for a metabolic analogue hypothesis. Comparitive Biochemistry and Physiology 79A: 61-72.**

Dissected and dried various tissues from 3 mussels collected from Georgetown and Corndorl Billabongs in the Magela Creek system, close to the Ranger Uranium minesite.

Concentration of radium-226 correlated with concentrations of alkaline earths (Ca, Mg and Ba) in dissected tissues.

Ra, Ca, Ba varied by an order of magnitude among tissues. Mg varied by factor of 2.

$^{226}$Ra Visceral mass 266.4 dpm/g dry (maximum value)

Visceral mass had highest activity in 2 of the 3 individauls – gut & contents?

Gills & mantle also relatively higher than foot, adductor muscles and kidney/heart.

Alpha track autoradiography, electron microprobe analyses, x-ray analysis and histological studies show Ra, Ca, Mg and Ba are mostly located in granular deposits dispersed through the body.

Granules may accumulate radium and act as store of exchangeable Ca. Also U-234, U-238, Th-230, Po-210 and Po-218 (Jeffree, unpublished data). So, they may serve as end sites for immobilization of metals for excretion and source of calcium for shell deposition.

Electron microprobe analysis peaks indicate that granules contain calcium phosphate and radium phosphate.

Cite Davy and Conway (1974) which reported lower Ra-Ca ratio in shell vs. mantle tissue - indicates possible selective retention of radium in body fluids and return to granules; also lower solubility of radium phosphate, relative to calcium phoshpate may lead to selective retention in granules.

**Jeffree, R. A. 1985. The accumulation of radium-226 by populations of the freshwater mussel, *Velesunio angasi*, from the Alligator Rivers Uranium Province, Northern Territory, Australia. Verhandlungen Internationale Vereinigung Theoretische und Angewandte Limnologie 22: 2486-2492.**

Radium-226 in mussels collected from billabongs (isolated river pools) in Magela Creek of the Alligator Rivers system in Australia. Georgetown Billabong receives nartural Ra-laden seepage from Ranger ore body.

Soft tissue samples dried at 70C for 12 hrs and radium-226 measured by the Lucas radon emanation method. Also measured Ca concentrations.

Size and Ca levels significant predictors of radium-226 levels. Mg signficant in one bilabong. Sex was not a significant predictor of radium level.

So this mussel accumulates radium as it grows/ages.

| | | | | |
|---|---|---|---|---|
| $^{226}$Ra | Georgetown Billabong | Water | 5 | pCi/L |
| | Corndorl Billabong | Water | <0.5 | |
| | Mudginberri Billlabong | Water | <0.5 | |
| | | Mussel Soft Tissue | 2.1-92.2 | pCi/g dry<br>77-3415 mBq/g dry<br>4,7-**204.7** dpm/g dry |
| Ca | | Mussel Soft Tissue | 10.1-94.8 | mg/g dry<br>(most <30) |
| Mg | | Mussel Soft Tissue | 0.65-2.60 | mg/g dry<br>(most <1.5) |

**Jeffree, R. A. and Simpson, R. D. 1986. An experimental study of the uptake and loss of Ra-226 by the tissue of the tropical freshwater mussel *Velesunio angasi* (Sowerby) under varying Ca and Mg water concentration. Hydrobiologia 139: 59-80.**

Exposed mussels to water with up to 50 pCi/L radium-226. Mussels accumulated radium up to 168-288 dpm/g dry (76-130 pCi/g dry).

Accumulation rate is linear with respect to period of exposure (28 and 56 day periods).

Size and sex do not affect accumulation rate.

Calcium in water possibly, competitively inhibits radium accumulation, suggesting Ra is metabolic analogue of Ca; Mg inhibition probably a different mechanism.

Biological half-life for Ra-226 is high in mussel soft tissue. Followed radium concentrations in experimental animals for up to 81 days-no decline in activity; also monitored non-experimental animals (with field-accumulated radium levels) for up to 286 days, and in a second experiment for 195 days - animals lost mass, but adjusted radium activity did not change, *i.e.* there was no loss of radium.

Most Ra taken directly from water (at least under experimental conditions - this conclusion needs more support).

**Jeffree, R. A. 1988a. Experimental comparison of radium-226 and calcium-45 kinetics in the freshwater mussel, *Velesunio angasi*. Verhandlungen Internationale Verieinigung und Angewandte Limnologie 23: 2193-2201.**

During laboratory incubation in Ca and Ra-free water for up to 175 days, mussels lost Ca, but not Ra.

Mussels in food (*Chlamydomonas*) vs. no food treatments did not differ in Ra levels - concluded uptake is principally from water rather than food... (*I hypothesize that phytoplankton may be a major source of Ra - according to other studies, plankton and particulate matted do scavenge/accumulate radium from the water column*).

**Jeffree, R. A. 1988b. Patterns of accumulation of alkaline-earth metals in the tissue of the freshwater mussel *Velesunia angasi* (Sowerby). Archive für Hydrobiologie 112: 67-90.**

Collected animals from 3 billabongs in the Magela Creek system, Australia

Maximum Ra-226 tissue concentration = ~**210** dpm/g dry Mudginberri Billabong)

Ra-226, Ba and Ca tissue concentrations are correlated with size; Mg concentration is not.

Positive correlation of Ra and Ba with Ca indicates support for metabolic analogue theory.

Accumulation rates: Ra>Ba~Ca>Mg correlate with stability constants of the hydrogen phosphates of the alkaline-earth metals, supporting hypothesis that differential rate of retention of earth metals in granules is related to their solubility.

**Jeffree, R. A. 1991. An experimental study of $^{226}$Ra and $^{45}$Ca accumulation from the aquatic medium by freshwater turtles (fam. Chelidae) under varying Ca and Mg water concentrations. Hydrobiologia 218: 205-231.**

Exposed snapping turtles to water with radium activity similar to Magela Creek for up to 30 days to evaluate uptake since turtles are included in diets of aboriginal peoples.

Levels of radium in treatment animals were higher in skin, bone and shell vs. control animals.

"The capacity of *E. dentata* to accumulate $^{226}$Ra from the aquatic environment is about two orders of magnitude [*actually a factor of 80*] less than that of the tissue of the freshwater mussel *Velesunio angasi* (Sowerby) exposed under similar experimental conditions."

Explanation: mussel skin more permeable, and they tend to accumulate radium in granules.

**Joshi, S. R. 1984. $^{137}$Cs, $^{226}$Ra and total U in fish from Lake Ontario, Erie, Huron, and Superior during 1976-1982. Water Pollution Research Journal of Canada 19: 110-119.**

Fish collected from several of the Great Lakes.

| | | | | |
|---|---|---|---|---|
| $^{226}$Ra | Rainbow Trout | 0.07 | pCi/g fresh | maxium; at a river mouth |
| | | | 0.02 | average |

**Justyn, J. 1973. Uptake of natural radioisotopes by aquatic organisms. Hydrobiological Studies 3: 145-171.**

Paper on Ra accumulation in aquatic biota under natural conditions in an experimental cascade below the outfall of an abandoned U mine and in other areas in Czechoslovakia.

"High cumulative capacities.found especially in filamentous algae, plankton, *Bryophyta* and several species of higher aquatic plants."

| | | | | | |
|---|---|---|---|---|---|
| $^{226}$Ra | mine area water | **292** | | pCi/L | maximum |
| | Plankton | 9500 | | pCi/g of ash | maximum |
| | | | 21,090 | dpm/g of ash | |
| | *Glyceria aquatica* | 14,540 | pCi/g of ash | | |
| | (plant in pond | **32,279** | dpm/g of ash | | |
| | (receiving mine | (1454) | | pCi/g dry solids | |
| | effluent; | 3228 | | dpm/g dry solids | |
| | 192 pCi/L in water) | | | | |

Hard to get data out of the paper.

**Kada, J. and Heit, M. 1992. The inventories of anthropogenic Pb, Zn, As, Cd, and the radionuclides 137Cs and excess $^{210}$Pb in lake sediments of the Adirondack region, USA. Hydrobiologia 246: 231-241.**

Nothing

**Kaufmann, R. F. and Bliss, J. D. 1977. Effects of phosphate mineralization and the phosphate industry on radium-226 in ground water of central Florida. EPA/520-6-77-010. U. S. Environmental Protection Agency, Las Vegas, Nevada.**

Analyzed available water table, Upper and Lower Floridan Ra-226 data from 1966 and 1973-1976 for Polk, Hardee, Hillsborough, Manatee and DeSoto Counties.

Water table aquifer in mineralized, unmined areas: geometric mean Ra-226 = 0.17 pCi/L; in mineralized, mined areas geometric mean Ra-226=0.55 pCi/L.

Upper Floridan: poorly documented

Lower Floridan: three populations, 0.7, 3 and 10 pCi/L

Floridan levels in Manatee and Sarasota are elevated: Manatee mean 4.52 pCi/L vs 1.23 in water table wells. Sarasota mean 15 pCi/L in water table and 7.5 pCi/L in Floridan

Notes that data is marginal in terms of number and distribution of sites.

See Kaufmann and Bliss (1978) for publication containing same data.

**Kaufmann, R. F. and Bliss, J. D. 1978. Radium-226 in ground water of west central Florida. Water Resources Bulletin 14: 1314-1330.**

Data from 1966 and 1973-1976 - see Kaufmann and Bliss (1977).

**Kernaghan, N.J., Ruessler, D.S., Miles, C.J., and Gross, T.S. Date Unknown. Bioaccumulation of methyl mercury by the freshwater mussel, Elliptio buckleyi. United States Geological Survey, Center for Aquatic Studies.**
Lab study of mercury accumulation from water and food (algae). Animals were collected from UF Fisheries Department experimental pond in Gainesville.

**Llewelling, B. R. and Wylie, R. W. 1993. Hydrology and water quality of unmined and reclaimed basins in phosphate-mining areas, west-central Florida. U.S. Geological Survey Water-Resources Investigations Report 93-4002.**

| | | | |
|---|---|---|---|
| $^{226}$Ra | 0.07-1.2 pCi/L | Creeks in unmined basins in Hillsborough, Polk and Hardee Counties | 1988-1990 |
| | <0.02-0.6 | Creeks in mined basins in Hillsborough, Polk and Hardee Counties | 1988-1989 |

**Lucas, H. F., Jr., Simmons, D., Markun, F., Farnham, J. and Keenan, M. 1979. Radon and radium retention by bluegill. Health Physics 36: 147-152.**
Injected radium into bluegill and measured bone and scale content using autoradiography.

**Lyman, G. H., Lyman, C. G., and Johnson, W. 1985. Association of leukemia with radium groundwater contamination. Journal of the American Medical Association 254: 621-626.**
Groundwater supplies sampled in 27 counties by State (for another study?).
Hillsbrough County identified as a county with "low" Ra exposure (see Fig. 2).
Polk , Hardee, Manatee, and Sarasota Counties were designated as areas of "high" exposure. Note other counties were included in study.
Contrasted leukemia incidence in high vs. low-exposure counties and found significant difference.

**Mahon, D. C. 1982. Uptake and translocation of naturally-occurring radionuclides of the uranium series. Bulletin of Environmental Contamination and Toxicology 29: 697-703.**
Sampled systems in British Columbia, Canada where naturally radioactivity is high.
Aquatic Food Chain

| | | | | | |
|---|---|---|---|---|---|
| $^{226}$Ra | Water | | | <0.02 | pCi/L |
| | Sediments | | | 2.2 | pCig dry |
| | Algae | | | 0.02 | |
| | Zooplankton | | | 0.3 | |
| | *Pisidium* (clam) | | 0.3 | | |
| | Rainbow Trout | Meat | <0.002 | | |
| | | | Bone | 0.02 | |
| | Finescale Sucke | Meat | <0.002 | | |
| | | | Bone | 0.02 | |

**Makarevich, T. A., Ostapenya, A. P, and Pavlyutin, A. P. 1996. Role of periphyton in the migration of radionuclides in a lake ecosystem. Hyrobiological Journal 32: 58-64.**
Measured $^{137}$Cs and $^{134}$Cs in Belorussian lake contaminated by Chernobly accident.
Periphyton shows highest activity (vs. filamentous green algae, *Glyceria maxima*, *Carex*, dragonfly nymph, "big-pond snail", and Chaoborina).

**Marsteller, D. 2002. Park's contamination level overstated, officials say. Published March 29, 200. Bradenton Herald, Bradenton, Florida.**
Article noting that EPA officials identified errors in a draft report, issued in 2001, on radioactive metals and heavy metals at Tenoroc Fish Management Arrea in Polk County.

**Michel, J. and Jordana, M.J. 1987. Nationwide distribution of Ra-228, ra-226 , Rn-22, and U in groundwater. Pages 227-240, in Graves, B. (ed.), Radon, radium, and other radioactivity in ground water. Lewis Publishers, Inc. Chelsea, Michigan.**
Used of a variety of federal and state data to assign risk for each US county of radon, radium-226 and uranium in groundwater serving as water supply.
Potential risk zones for Ra-226 include west-central FL, Appalchians, upper Midwest, Rocky Mts., and Sierra/Coastal ranges.

**Miller, R. L. and Sutcliffe, H., Jr. 1985. Occurrence of natural radium-226 radioactivity in ground water of Sarasota County, Florida. Water Resources Investigations Report 84-4237. Prepared in cooperation with Sarasota County, Florida. U. S. Geological Survey, Tallahassee, Florida.**
Highest levels seen in the intermediate aquifer; max value = 110 pCi/l in a saline sample. Apparently mineralized water (marine-like from saltwater encroachment or calcium magnesium strontium sulfate bicarbonate type) causes elevated radium levels.

**Miller, R. L., Kraemer, T. F., and McPherson, B. F. 1990. Radium and radon in Charlotte Harbor estuary, Florida. Estuarine, Coastal and Shelf Science 31: 439-457.**

Collected water samples from Charlotte Harbor (and lower Peace and Myakka Rivers) for radium-226 and radon analysis. Also measured Ra activity in oysters shells.

Water activities highest in upper estuary/tidal river reaches vs freshwater reaches and Gulf of Mexico/Lower estuary.

Radium-226 activity in water "can exceed 500 dpm/100L, and activities above 150 dpm/L are common". Maximum was 548 dpm/100L in tidal Myakka River. Note 500 dpm/100L = 22.5 pC/L; 100 dpm/100L= 4.5 pCi/L;

| | | | |
|---|---|---|---|
| $^{226}$Ra | 0.1-0.2 pCi/L | **Peace River at State Road 761**<br>See Table 1. | 1983-1984 |
| | 0.5-1.0 | **Peace River near mouth**<br>See Table 1 | 1982-1984 |
| $^{226}$Ra | 0.07-3,6 dpm/g<br>0.03-1.66 pCi/g | **OYSTER SHELLS** (dried; collected live)<br>Highest values measured in tidal reaches of Peace and Myakka Rivers. See Figure 7, p. 451. Peak values was at Myakka site. | |

**Mirka, M. A., Clulow, F. V., Dave, N. K., and Lim, T. P. 1996. Radium-226 in cattails, *Typha latifolia*, and bone of muskrat, *Ondatra zibethica* (L.), from a watershed with uranium tailings near the City of Elliot Lake, Canada. Environmental Pollution 91: 41-51.**

Radium in cattails and muskrat bone near Quirke Lake, Canada (and at sites nearby and some distance away-controls). Note that muskrats are herbivorous and *Typha* is an important food and nesting plant for the species.

| | | | |
|---|---|---|---|
| $^{226}$Ra | <u>Study Area-High</u> | | |
| | 2-26 | pCi/L | Water |
| | 33.1 | dpm/g dry *Typha* (whole plant) =14.9 pCi/g dry; | |
| | 16.6 | dpm/g dry leaves | |
| | 14.9 | dpm/g dry stems | |
| | 68.1 | dpm/g dry roots | |
| | 20.6 | dpm/g dry Muskrat bone = 9.3 pCi/g dry | |
| | <u>Study Area-Low (Dunlop and Elliot Lakes)</u> | | |
| | 0.2-2 | pCi/L | Water |
| | Not sampled | | *Typha* |
| | 4.9 | dpm/g dry Muskrat bone = 2.2 pCi/g dry | |
| | <u>Local Control Site</u> | | |
| | 0.2 | pCi/L | Water |
| | 1.3 | dpm/g dry *Typha* (whole plant) = 2.6 pCi/g dry | |
| | 4.7 | dpm/g dry Muskrat bone = 2.1 pCi/g dry | |
| | <u>Distant Control Site</u> | | |
| | 0.2 | pCi/L | Water |
| | 0.9 | dpm/g dry *Typha* (whole plant) = 0.4 pCi/g dry | |
| | 0.09 | dpm/g dry Muskrat bone = 0.04 pCi/g dry | |

Did dose estimate for consumption of muskrat and found to be OK.

**Montalbano, F., III, Thul, J. E., and Bolch, W. E. 1983. Radium-226 and trace elements in mottled ducks. Journal of Wildlife Management 47: 327-333**

Collected 20 mottled ducks from settling basin near Bartow and 10 ducks from Lake Okeechobee in 1980. Also collected a substrate sample (composite from 3 sites) at settling pond

| | | | |
|---|---|---|---|
| $^{226}$Ra | 21.0 | pCi/g dry | Settling pond sediment composite sample |
| | 23.8 | pCi/g dry | Mean for 10 other central Fl phosphate settling areas reported by (Roessler et al. 1979). |
| | 0.003 | pCi/g wet | Duck muscle (reported as 3.08 pCi/kg wet) from settling pond on phosphate mine near Bartow |
| | 0.0009 | pCi/g wet | Duck muscle (reported as 0.86 pCi/kg wet) from Lake Okeechobee |

Used water radium standard (5 pCi/L) and water consumption rate (1.2 L/day) to estimate that an individual would ingest 2190 pCi/yr. "To obtain a similar amount from eating contaminated duck flesh, it would be necessary to eat 1.95 kg of duck/flesh/day. Therefore, levels of $^{226}$Ra that might be ingested with mottled duck flesh are insignificant."

**Morales, D., Bolch, W.E., Jr., de la Cruz, J., and Nall, W. 2002. Dose potential fro Consumption of select radionuclides (ra-226, Pb-210) and metals (Cd, Hg, Pb) in central Florida phosphate mineralized region freshwater fish protein, final report.**

**Prepared for the Florida Institute of Phosphate Research, Bartow, Florida.**

Analyzed samples of 5 fish species from four 4 unreclaimed lakes (Floral Lake-augmented, Saddle Creek, Dover Park & Tenoroc Lake #5), 2 reclaimed lakes (IMC Fort Green #845 & Medard Park ), 3 natural lakes (Lake Arietta, Lake Hunter & Walk-in-Water), and 1 reservoir (Lake Manatee).

Bass, catfish and tilapia subsampled fillets for analysis. Panfish specimens too small to fillet were scaled, finned, beheaded and butterflied, so some bone material was included.

Ra-226 found in all species in all lakes. Non-detect (215 of 434 samples) were assigned a value of one-half the detection limit.

| | | |
|---|---|---|
| Mean for 434 samples | 0.028 | pCi/g wet |
| | 0.062 | dpm/g wet |
| Range for all samples | 0.0004 – 0.392 | pCi/g wet |
| | 0.0009-0.87 | dpm/g wet |

Data from P886 study indicates dry mass for fillets is ~20% of wet mass and dry mass for bone tissue is ~30% of wet mass. Using a 20% conversion factor, the mean Ra-226 activity of 0.028 pCi/g wet = 0.31 dpm/g dry and the range = 0.0045-4.4 dpm/g dry.

See report for data on individual lakes and species and Pb-210 data.

**Moura, G., Guedes, R., and Machado, J. 1999. The extracellular mineral concretions in *Anodonta cygnea* (L.): different types and manganese exposure-caused changes. Journal of Shellfish Research 18: 645-650.**

Review in Introduction section covers use of granules for storage of insoluble Ca for shell production. May also be used for pH buffering, and detoxification of heavy metals.

**Muncaster, B.W., Hebert, P.D.N., and Lazar, R. 1990. Biological and physical factors affecting the body burden of organic contaminants in freshwater mussels. Archive of Environmental Contamination and Toxicology 19: 25-34.**

Review of mussel accumulation of toxic compounds. Discussion section includes review of size/body burden relationships.

**Myers, O. B., Marion, W. R., O'Meary, T. E., and Roessler, G. S. 1989. Radium-226 in wetland birds from Florida phosphate mines. Journal of Wildlife Management 53: 1110-1116.**

See O'Meary *et al.* (1986) report.

**National Council on Radiation Protection and Measurement. 1991. Effects of ionizing radiation on aquatic organisms. NCRP Report No. 109. Bethesda, Maryland.**

NEED TO LOOK AT.

**O'Meary, T. E., Marion, W. R., Roessler, C. E., Roessler, G. S., Van Rinsfelt, H. A., and Myers, O. B. 1986. Environmental contaminants in birds: phosphate-mine and natural wetlands. University of Florida, Gainesville, Florida. Prepared for the Florida Institute of Phosphate Research, Bartow, Florida, FIPR-05-003-045.**

Measured radium-226 and trace elements in four bird species (double-crested cormorants, common moorhens, wood ducks, and mottled ducks) in settling area wetlands from mined areas and un-mined areas (Lakes Newnans, Orange and Kissimmee) in north and central FL.

Measured soft tissue (muscle, liver, kidney) and bone activity (muscle sampled from wood and mottled ducks only).

Also collected water and substrate samples and diet items (plants, inverts and fish).

Tissues freeze-dried and ground; bone and fish samples were ashed.

Also submitted some samples to a commercial lab.

Calculated annul radiation doses to individuals assuming a conversion factor of 1.1 x $10^{-3}$ mrem/pCi ingested.

Mean $^{226}$Ra Substrate Central 0.2 pCi/g dry Control
23.4 Settling
North 1.4 Control
14.7 Settling

Water-TotCentral 0.08 (0.09) pCi/L Control
2.0 (24) Settling
North 0 Control
0.4 Settling
() = commercial lab

Bird Bone Central 0.05-0.3 pCi/g ash Control
0.5-4.4 Settling
North 0.2-0.7 Control
0.2-1.9 Settling
Bone of ducks had higher levels than cormorants of moorhens; possibly due to diets or ingestion of sediment?

Duck Muscle Central 0.01 pCi/g ash Control
0.2 Settling
North 0.002 Control
0.009 Settling

Diet? Central 0.1 pCi/g dry Control
0.4 Settling
North 0.03 Control
1.2 Settling

? Duck bone (0.3) pCi/g ash Control
(1.1) Settling
(0.1) pCi/g dry Control
(2.4) Settling
()=commercial lab

Central Green Algae 9 pCi/g dry Settling
Duckweed 9 Settling
Hydrilla 5.5 Settling
Watergrass 0.2 Control
Wild celery 0.1 Control

Central Bladderwort 4.2 Settling
Spatterdock 0.02 Control
Brasenia 0 Control
Duckweed 0.35 Control
North Hydrilla 1 Control

Central Bryozoan 1.6 pCi/g dry Settling
Pomacea 0.2 Control
Planorbid 0.1 Control
Beetle 0.6 Settling
Sunfish 0.03 Control
Sunfish 0.1 Settling
Gambusia 0.4 Settling
North Planorbid 0.05 Control
Shad 0.05 Control
Cranefly 1.6 Settling

Fish data are for whole fish.

Radiation dose to humans: assume consumption of 1.5 kg/yr and a maximum intake of 10 kg/yr. Dose from radium-226= 0.001 mrem/yr from northern Fl control areas to 0.01 mrem/yr for consumers of ducks from central FL settling areas.
Refers to Stabin (1983) who derived working value of 3 mrem of radium-226 per year of 2700 pCi per year.

"More recently the Standards Committee of the Florida Phosphate-related Radiation Task Force (1984) has recommended 500 mrem/yr as the appropriate standard for all exposure of individuals of the general public and has suggested that intake of radium-226 be limited to 20 pCi/day. If the intake permitted by the Drinking Water Standard (10 pCi/day, Environmental Protection Agency 1976) is subtracted, this corresponds to 10 pCi/day (3700 pCi/year) or 5 mrem/year from ingestion sources other than drinking water"

"...at the maximum average concentration of 6 pCi/kg that we found, it would require an intake of over 450 kg/year (980 pounds/year) to achieve an annual effective dose equivalent of 3 mrem. Thus, even at maximum hypothesized consumption rates, waterfowl meat from settling ponds would not represent a health risk to humans."

"... it is unkown whether the observed radium concentrations in bird bone would constitute a health hazard to birds."

Note: values in report are greater, but same order of magnitude as those reported by Montalbano *et al.* (1980).

**Oural, C.R., Upchurch, S.B., and Brooker, H.R. 1988. Radon progeny as sources of gross-alpha radioactivity anomalies in ground water. Health Physics 55: 889-894.**
Discusses problems with gross-alpha analyses that may introduce variability in results.

**Owen, C. 2000. Memorandum to Marty Kelly on raw water quality data for the Hillsborough River Reservoir. City of Tampa, Water Department, Tampa, Florida.**

| | | | |
|---|---|---|---|
| Gross | 1.3 pCi/L | Hillsborough River Raw | August 1999 |
| Alpha | <1.3 | Hillsborough River Raw | September 1999 |
| | <1.3 | Hillsborough River Raw | October 1999 |
| | 1.8 | Hillsborough River Raw | November 1999 |

**Polikarpov, G. G. 1966. Radioecology of aquatic organisms. North-Holland Publishing Company, Amsterdam.**
NEED TO LOOK AT

**Pritchard, P. C. H., and Bloodwell, J. M. 1986. Multidisciplinary study of radionuclides and heavy metal concentrations in wildlife on phosphate mined and reclaimed lands. Prepared by the Florida Audubon Society, Maitland, Florida, for the Florida Institute of Phosphate Research, Bartow, Florida. FIPR-05-017-042.**
Good review of previous studies (see pp. 4-7).
Sampled alligator, Florida softshell (Trionyx), snapping turtle (*Chlydra*), cooters (*Pseudemys* spp.) and armadillo (*Dasypus*) and one otter from mine-impacted, mineralized-unmined, and unmineralized lands in central Florida.

| | | | |
|---|---|---|---|
| $^{226}$Ra | 0.2 - 1.7 | pCi/g ash | Alligator neck tissue (including bone, skin; also femurs; one case used other tissues) |
| | <0.2 - 3.8 | | Softshell turtle (entire shell) |
| | <0.2 - 8.7 | | Cooters (shells from dead animals) |
| | 3.8 | | Snapping turtle (1 whole animal, excluding gut) |
| | 1.5 max | pCi/g ash | Armadillo (intact tail) |
| | 0.4 | pCl/g ash | Otter bone |

**Pyle, G. G., and Clulow, F. V. 1997. Non-linear radionuclide transfer from the aquatic environment to fish. Health Physics 73: 488-493.**
Collected white suckers from 11 lakes that directly or indirectly receive U from mine activities and 5 nearby control lakes - all near Elliot Lake, Ontario. Sampled suckers because previous studies show they accumulate radionuclides as a result of their bottom-feeding habits.

| | | | | |
|---|---|---|---|---|
| $^{226}$Ra | Water | ~5400 | pCi/l | max |
| | Sediments | ~200 | pCi/g | max |
| | WhiteSucker Bone | ~3 | pCi/g dry | max |
| | White Sucker Muscle | ~0.1 | pCi/d dry | max |

**Pyle, G. G., and Clulow, F. V. 1998. Radioinuclide equalibria between the aquatic environment and fish tissues. Journal of Environmental Radioactivity 40: 59-74.**
Water, sediments and white sucker (a common bottom feeder) sampled from Quirke Lake, near Elliot Lake in Ontario, Canada. Lake is near four tailings (mill and waste) areas and receives radionuclides in runoff, by leaching and by atmospheric deposition.

| | | | |
|---|---|---|---|
| Water | 2.2 | pCi/L | |
| Sediments | 27.3 | dpm/g dry | |
| Sucker Bone | 0.7 | dpm/g dry | geometric mean |
| Sucker Muscle | 0.2 | dpm/g dry | geometric mean |

Radium was approximately 2-4 times higher in bone than muscle

**QST Environental, Inc. 1998. Draft final report: Four Corners mine monitoring, year two, July 1996-June 1997. Tampa and Gainesville, Florida.**

| | | |
|---|---|---|
| $^{226}$Ra | 0.1-1.3 pCi/L | Creeks in Upper Manatee River watershed, prior to mining |
| | 0-1.9 | Creek in Upper Manatee River watershed, after mining. |

**Roessler, C. E., Smith, Z. A., Bolch, W. E., and Prince, R. J. 1979. Uranium and radium-226 in Florida phosphate materials. Health Physics 37: 269-277.**

Ore from central FL has higher U-238 and Ra-226 levels than ore from north FL.
Ammoniated phosphates (AP) fertilizer samples had relatively low levels of Ra-226, but "significant U-238". Triple superphosphate (TSP) fertilizer had significant concentrations of Ra and U (U activity was 2-15 times the Ra activity).

| | | | | | |
|---|---|---|---|---|---|
| $^{226}$Ra | Central FL | Matrix | | 83.5 | dpm/g dry |
| | | AP Fertilizer | | 9.1 | |
| | | TSP Fertilizer | 43.7 | | |

**Rope, S. K. and Whicker, F. W. 1985. A field study of Ra accumulation in trout with assessment of radiation dose to man. Health Physics 49: 347-257.**

Stocked 2 settling ponds at uranium mines in Wyoming with trout. Another set of ponds had been stocked previously. Sampled water and fish from both systems for radium-226 activity.

| | | | |
|---|---|---|---|
| $^{226}$Ra | Water (filtered) | 12-23 | pCi/L |
| | Trout bone | ~0.4-6 | pCi/g wet |
| | Trout skin/fins | ~0.1-0.9 | pCi/g wet |
| | Flesh | ~0.006-0.03 | pCi/g wet |

"Calculated dose based on consumption of one fish/week for 50 yrs: maximum 83 mrem/yr. "Comparison of the calculated dose equivalent rates with radiation protection standards suggests that the dose to man from ingested $^{226}$Ra in fish would not preclude the establishment of a recreational lake at this site."

**Schelske, C.L., Peplow, A., Brenner, m and Spencer, C.N. 1994. Low-background gamma counting: applications for 210Pb dating of sediments. Journal of Paleolimnology 10: 115-128.**

$^{226}$Ra in uppermost samples from sediment cores(see Figure 2).

| | | | |
|---|---|---|---|
| Lake Lucerne | surface core | ~4 | dpm/g dry |
| Whitefish Lake | | ~2 | |
| Lake Rowell | | ~23 | |

**Scott, R.C. and Barker, F.B. 1962. Data on uranium and radium in ground water in the United States 1954 to 1957. Geological Survey Professional Paper 426. United States Department of the Interior Geological Survey, Washington, D.C.**

Separated US into 10 regions and calculated range and median uranium and radium concentrations.
Data are not well presented.

**Shannon, L. V. and Cherry, R. D. 1971. Radium-226 in marine phytoplankton. Earth and Planetary Science Letters 11: 339-343.**

Phytoplankton in waters off South Africa.

| | | |
|---|---|---|
| $^{226}$Ra | 7.7 x10$^{-12}$ g/g dry | Mean for Agulhas Current |
| | 7.7 | pCi/g dry |
| | 17.1 | dpm/g dry |
| | 1.0 x10$^{-12}$ g/g dry | Mean for other areas (exluding |
| | 1 | pCi/g dry one site) |
| | 2.2 | dpm/g dry |

Zooplankton in waters off South Africa.

| | | |
|---|---|---|
| $^{226}$Ra | 0.3 x10$^{-12}$ g/g dry | Mean for all sites |
| | 0.3 | pCi/g dry |
| | 0.7 | dpm/g dry |

**Stabin, M. G. 1983. Radium-226 in waterfowl associated with Florida phosphate clay settling areas. M.E. Thesis, University of Florida, Gainesville, Florida.**

Good review.
Sampled ducks in 7 north and central control (Lakes Newna, Lochloosa and Kissimmee) and mined wetland areas. Wood ducks from northern sites, Florida ducks from central sites.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $^{226}$Ra | Northern FL | Natural Wetland | Sediment | | 1.0 | pCi/g dry | | |
| | | | Water | | | nd | | |
| | | | | Duck Muscle | | | 0.002 | pCi/ g fresh |
| | | | | Duck Bone | | | 0.5 | pCi/ g ash |
| | | Settling Area | | Sediment | | 14.5 | pCi/g dry | |

| | | | | |
|---|---|---|---|---|
| | | Water | 0.5 | pCi/L |
| | | Duck Muscle | 0.005 | pCi/g fresh |
| | | Duck Bone | 2.0 | pCi/g ash |
| Central FL | Natural Wetland | Sediment | 0.2 | pCi/g dry |
| | | Water | 0.08 | |
| | | Duck Muscle | 0.004 | pCi/ g fresh |
| | | Duck Bone | 0.4 | pCi/ g ash |
| | Settling Area | Sediment | 23.9 | pCi/g dry |
| | | Water | 4.1 | pCi/L |
| | | Duck Muscle | 0.008 | pCi/g fresh |
| | | Duck Bone | 3.1 | pCi/g ash |

**Stover, B. J., Atherton, D. R. and Arnold, J. S. 1957. Comparative metabolism of Ca-45 and Ra-226. Proceedings of the Society for Experimental Biology and Medicine 94: 269-272.**

Early paper on radium as calcium analog.

Injected beagle pup with tracers; took blood samples, killed and dissected animal after 24 hrs.

Both Ra and Ca were retained at greater than 90%, reflecting the growth phase of the pup. Deposited in bone and teeth.

**Swanson, S. M. 1983. Levels of $^{226}$Ra, $^{210}$Pb and $^{TOTAL}$U in fish near a Saskatchewan uranium mine and mill. Health Physics 45: 67-80.**

Radium-226 and other radionuclides in water and fish in Canadian lakes.

Fish collected from Beaverlodge Lake, which received radionclide-tainted runoff from uranium mine tailings, and Lake Fulton, which did not.

For Ra analysis, larger fish were separated into skin, filets; smaller fish (300-400g) species analyzed whole

ANOVA indicated higher activity in Beaverlodge Lake, but also differences among Species.

Activity higher in skin or bone than in fillets.

| | | | | |
|---|---|---|---|---|
| $^{226}$Ra | Water | 0.1 | pCi/L | Fulton Lake (control) |
| | | 2.9-176 | | Tailings System |
| | | 1.5-2.2 | | Beaverlodge Lake |
| | Whole Fish | not det | pCi/g ash | Fulton Lake (control) |
| | | 4.7-56.3 | | Beaverlodge Lake |
| | Fish Bone | <1 | pCi/g ash | Fulton Lake (control) |
| | (Large) | <1-~11 | | Beaverlodge Lake |
| | Fish Flesh | <<1 | pCi/g ash | Fulton Lake (control) |
| | (Large) | <1 | | Beaverlodge Lake |

Note: large fish data is not presented very well in the paper! Hard to figure out!

**Stone, S. S. 2000. Letter dated January 11, 2000 to Marty Kelly on archived water quality data for the Peace River. Peace River/Manasota Regional Water Supply Authority, Arcadia, Florida.**

| | | | |
|---|---|---|---|
| $^{226}$Ra | 0.3 pCi/L | Water Plant at Ocean Blvd. | 1987 |
| | 0.6 | Peace River Raw | 1987 |
| | 0.6 | N. Port Water Plant | 1987 |

**Swanson, S. M. 1985. Food-chain transfer of U-series radionuclides in a northern Saskatchewan aquatic system. Health Physics 49: 747-770.**

Sampled water, insects, fish in streams and lakes near U mill tailing treatment area in Canada. Tailings system and Beaverlodge Lake receive U input.

| | | | | |
|---|---|---|---|---|
| $^{226}$Ra | Water | up to 116 pCi/L | | Tailings system |
| | | 1.6 | | Beaverlodge Lake |
| | Sediments | 26 | pCi/g wet | Beaverlodge Lake |
| | | 0.5 | | Control Lake |
| | | up to 22 | | Tailings system |
| | Aquatic Insects | 0.2-23 | pCi/g wet | Tailings system |
| | | 0.2-3.5 | | Control creek |

|  |  |  |  |
|---|---|---|---|
| Forage | 0.5-1.6 | pCi/g wet | Tailings creek |
| Fish (whole) | 0.11 |  | Beaverlodge Lake |
|  | 1.1-3.8 |  | Ace Creek |
| Forage | 18-46 | pCi/g ash | Tailings creek |
| Fish (whole) | 4.1 |  | Beaverlodge Lake |
|  | 23-108 |  | Ace Creek |
| Large Fish | .005-0.3 | pCi/g wet | Flesh- Beaver Lodge Lake |
| (whitefish& | 0.5-2.7 | pCi/g ash | Flesh-Beaver Lodge Lake |
| sucker ) | 0.8-2.2 | pCi/g wet | Bone-Beaver Lodge Lake |
|  | 3-7.8 | pCi/g ash | Bone-Beaver Lodge Lake |

Large fish values were significantly lower in two control lakes

"Dose to humans from regular consumption of Beaverlodge fish was relatively small (Table 21)." "Because actual consumption rates in the Beaverlodge area are considerably less than one serving per week, the risk is likely close to that associated with background radiation."
'Radionuclide content decreases with successive trophic level in this study"

**Torres, L. M. 1988. Radium-226 in plankton on the west Florida shelf. M.S. Thesis, University of South Florida, Tampa, Florida.**
Plankton collected in three Gulf transects: off the Suwanee River, Crystal and Chassahowitzka Rivers and Tampa Bay.
Higher values recorded at nearshore stations in 2 of 3 transects.

|  |  |  |  |
|---|---|---|---|
| $^{226}$Ra | Phytoplankton | 0.1-115 | dpm/g dry<br>0.05-51.8 pCi/g dry |
|  | Zooplankton |  | 0.1-63dpm/g dry<br>0.05-28.4 pCi/ g dry |

**Turekian, K. K. and Cochran, J. K. 1986. Flow rates and reaction rates in the Galapagos Rise spreading center hydrothermal system as inferred from $^{228}$Ra/$^{226}$Ra in vesicomyid clam shells. Proceedings of the National Academy of Sciences USA 83: 6241-6244.**
Radium values in deep-see clams: 0.052 and 0.091 dpm/g.

**Twining, J. R. 1988. Radium accumulation from water by foliage of the water lily, *Nymphaea violacea*. Verhandlungen Internationale Vereinigung Theoretische und Angewandte Limnologie 23: 1954-1962.**
Mesocosm study of uptake of radium by water lily (and associated epiphyton) from Corndorl Lagoon in the Magela Creek floodplain, Australia. Area is downstream from U mine.
Rapid uptake and loss indicated surface adsorption or uptake by epiphyton are primary mechanism for accumulation of radium, rather than actually uptake by lily.

**Twining, J. R. 1989. Principal coordinate analysis of the distribution of radium-226 between water, sediment and the waterlily, *Nymphaea violacea* (Lehm), in the vicinity of a uranium mine in the Northern Territory, Australia. Journal of Environmental Radioacitivy 10: 99-113.**
Lily is a component of the Australian aboriginal diet.
Radium measured in water, sediments and lily tissues at 4 sites in the Magela Creek system.

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
| $^{226}$Ra | Laminae | 5.3-25.5 | mBqi/g dry |  | 0.3-1.5 dpm/g dry |  |
|  | Petioles | 7.4-16.7 |  |  | 0.4-1.0 |  |
|  | Peduncles |  | 4.2-17.4 |  |  | 0.3-1.0 |
|  | Flowers | 2.8-8.2 |  |  | 0.2-0.5 |  |
|  | Fruit |  | 1.7-2.9 |  |  | 0.1-0.2 |
|  | Rhizome (whole) | 44.0 |  | (only 1 site) |  | 2.6 |
|  | Roots |  | 8.9-189 | (differing portions) | 0.5-11.3 |  |

Also looked at senescence effect in lily and other species; higher in older leaves

|  |  |  |  |  |
|---|---|---|---|---|
| $^{226}$Ra | *Nymhaee* | 4.2 |  | dpm/g dry |
|  | *Eleocharis* |  | 1.9 |  |
|  | *Pseudoraphis* | 3.3 |  |  |
|  | *Polygonum* |  | 2.4 |  |
|  | *Fimbrisylis* |  | 0.6 |  |

**Twining, J. R. 1993. A study of radium uptake by the water-lily, *Nymphaea violacea* (Lehm) from contaminated sediment. Journal of Radioactivity 20: 169-189.**
Introduction provides overview of radium accumulation in plants.
For study, collected plants from field and grew in lab in radium-spiked sediments.
Radium accumulated on surface of roots and rhizomes; foliar accumulation attributed to uptake from water contaminated by radium in sediments

**Ulferts, A. 1999. EPA to set gas toxicity limit for well water. St. Petersburg Times, February 14, 1999. St. Petersburg, Florida.**
Newspaper article on proposed EPA limits on radon in drinking water.
Possible standard: 4,000 pCi/L.

**Upchurch, S.B., Oural, C.R., Foss, D.W., and Brooker, H.R. 1991. Radiochemsitry of urnanium-series isotopes. Publication No. 05-022-092, Florida Institute of Phosphate Research, Bartow, Florida.**

| | | |
|---|---|---|
| 226Ra | 13 Surficial aquifer monitor wells | 0.15-3.37 pCi/L |
| | 13 Floridan aquifer monitor wells | 0.2-2.89 pCi/L |

**Upchurch, S. B., Linton, J. R., Spurgin, D. D., and Brooker, H. R. 1981. Radium-226 in central Florida aquatic organisms. FL-USF-81-126. University of South Florida, Tampa, Florida.**
Measured Ra-226 in water, plants, inverts, and fish from 11 central FL sites (in Pasco, Hillsborough, Polk Manatee, and Sarasota Counties)

| | | | | |
|---|---|---|---|---|
| $^{226}$Ra | Water | 0.7 &1.5 | pCi/L | Lake on IMC property near Bartow |
| | | 1.2 | | Lake in Mary Holland Park near Bartow |
| | | 0.8 | | Lake on IMC property near Bartow |
| | | 1.6 | | Alafia River at Lithia Springs |
| | | 1.1 | | Lake Manatee at State Road 64 |
| | | 0.5 | | Cypress Creek at State Road 54 |
| | | 0.8 | | Lake at State Road 52 and County Road 587 |
| | | 0.5 | | Myakka River at State Road 780 |
| | Plants | 0.2-**25** | pCi/g dry | 4 sites |
| | | 25.9 | | *Elodea*, |
| | | 93.0 | | Filamentous algae, |
| | | 9.7 & 15.9 | | *Myriophyllum*, |
| | | 2.1 | | Najas quadalupensis |
| | | 0.2 | | *Typha* |
| | Inverts | 0.1 | | *Paleomonetes palusdosus* |
| | | 0.4 | | *Procambarus phalanx* |
| | Herb-Fish | 0.1-5 | | Shad, molly, Tilapia |
| | Carn-Fish | 0.01-1.7 | | Numerous spp. (*Gambusia*-high<br>Bass, bluegill, etc.in tabel) |
| | | Ave=0.2 | | Control area |
| | | Ave=0.2 | | Unmined, phosphate-bearing terranes |
| | | Ave=0.4 | | Mined lands |

See table 3 for Ra-226 content for various fish species (bluegill, bass, redear, gar, crappie, etc.)

No evidence of biomagnification.

" Based on our present understanding, is seems that if only larger fish are eaten by man, if the majority of radium-226 is in bone, and if fish constitute a small part of human diet, there should be minimal hazard to man. It seems that fish from most of the environments sampled are relatively low in radium anyway. Fish from lands affected by phosphate mining constitute the only area of concern and a study should be undertaken to determine the use of fish in human diet from these areas.

Of more immediate concern is the impact on the remainder of the food chain. No overt impacts can be detected from the superficial examinations we have given the sample sites...
...chronic exposure to radium may have a subtle, negative impact on the aquatic plants and animals."

**Upchurch, S. B., Spurgin, D. D., Linton, J. R., and Brooker, H. R. 1985. Natural radionuclides in Tampa Bay, Florida. Pages 595-613, in Tampa Bay Area Scientific Symosium, Bellweather Press, Edina, Minnesota.**
Summary paper which lists/cites data from other sources.

| | | | |
|---|---|---|---|
| $^{226}$Ra | <u>Water</u> | | |
| | Cypress Creek | 0.5 | pCi/L unfiltered |
| | Alafia River at Lithia | 0.5-1.6 | |
| | Little Manatee River | 0.8 | |
| | Lake Manatee | 0.3-1.1 | |
| | Tampa Bay sites | 0.3-2.0 | |
| | <u>Freshwater Biota</u> | See Upchurch et al. 1981 | |
| | <u>Estuarine Inverts (whole)</u> | | |

| | | | | |
|---|---|---|---|---|
| *Penaeus* sp. | | 0.4 | max | pCi/g dry 0.9 dpm/g |
| *Melongena* | | 0.2 | | pCi/g dry 0.4 |
| Misc. Mollusca | 0.3 | | pCi/g dry 0.7 | |
| Callinectes sp (blue crab) | 0.6 | max | pCi/g dry 1.3 | |
| <u>Estuarine Fish (whole & fillets)</u> | | | | |
| Whitting (whole) | 0.9 | max | pCi/g dry 2.0 | |
| Tongue sole (whole) | 0.4 | max | pCi/g dry 0.9 | |
| Tongue sole (fillet) | 0.007 | max | pCi/g wet 0.02 /wet | |
| Catfish (fillet) | | 0.002 | | pCi/g wet 0.004 /wet |

**Upchurch, S. B. and Randazzo, A. F. 1997. Environmental geology of Florida. Pages 217-249 in Randazzo, A. F. and Jones, D. S. (eds.) The Geology of Florida. University Presses of Florida, Gainesville.**
"The ulitimate source of most radioactivity in Florida is U indcorporated in carbonate-fluorapatite at the time of formation."
In FL, radium, polonium-210 and radon-22 are problem alpha emitters.
Radium-226 is relatively high in surficial and Upper Floridan in west-central FL. Derived From weathering of phosphorites and transport; also a salt effect.
Highest activities measured for Po are in Hillsborough County.

**Van Der Borght., O. 1963. Accumulation of radium-226 by the freshwater gastropod *Lymnaea stagnalis* L. Nature 197: 612-613.**
Dosed snails with 0.04 uCi/L solution of radium-226; let them take it up (accumulated more than 90% of the dosed radium) and measured accumulation in tissues.
Concentration Factors (fresh weight to water):

| | | |
|---|---|---|
| Newly formed shell | 1,277 | |
| Older shell | | 376 |
| Soft parts | 140 | |
| Whole animals | 108 | |
| Blood | | 21 |

Also conducted a "release" study for up to 3 days by putting animals in Ra-free water – found that they did not lose much of the incorporated radium.

**Van Der Borght., O. and Puymbroeck, S. V. 1964. Active transport of alkaline earth ions as a physiological base of the accumulation of some radionuclides in freshwater molluscs. Nature 204: 533-534.**
Early paper on active uptake of radionuclides.

**Vaughn, C.C., and Hakenkamp, C.C. 2001. The functional role of burrowing bivalves in freshwater ecosystems. Freshwater Biology 46: 1431-xxxx.**
Freshwter bivalves are filter-feeders. Some taxa are also pedal feeders – they use cilia on foot to collect buried organic matter. Some claim that pedal feeding is "almost universal in juvenile bivalves" and that adults of some small species (e.g., sphaerids) also pedal feed. Corbicula juveniles and adults pedal-feed. A study of unionids in MI stream indicated animals were consuming 80% deposited and 20% suspended material (Raikow & Hamilton 2000).

**Veckon, A. 1999. Telephone conversation on March 5, 1999 regarding radioactivity values for water at the Hillsborough County Lake Park Pump Station.** Gross 2.7 pCi/L Note: 95-99% of Lake Park Station water1996
Alpha is from Section 21 Well Field.

**Von Gunten, H. R., Surbeck, H. and Rossler, E. Uranium series disiquilibrium and high thorium and radium enrichments in karst formations. Environmental Science and Technology 30: 1268-1274.**
Paper documents lead-210/radium-226 disequilibrium similar to that seen in some FL lakes.

**Wahl, R. D. 1980. A study of the amounts of radium-226 found in fish and waters of Tampa Bay, Florida. M. A. Thesis, University of South Florida, Tampa, Florida.**

| | | | |
|---|---|---|---|
| $^{226}$Ra | Tampa Bay water (filtered) | 1.25-1.94 pCi/L | |
| | Fish filets | <0.005 pCi/g | |
| | Whole fish | | 0.04-0.16 pCi/g |

**Problem with study: distilled/DI water used for water analyses had radium level of 0.4 pCi/L. Page 35 says water used for fish sample processing had even higher radium levels- up to 113 pCi/L.

**Walters, M.O. 1995. Radium in coastal Sarasota County ground water. Ground Water Monitoring and Remediation 15:114-118.**
Data obtained from samples submitted to the Environmental Section the Health and Rehabilitative Services of the State of Florida by private drinking well owners in 1986, and samples collected by HRS staff in 1987.
Data are considered representative of the intermediate aquifer.

| | | |
|---|---|---|
| $^{226}$Ra | Well water | 1.4 – 29.5pCi/L |
| $^{228}$Ra | Well water | 0.3 – 2.5 |

**Warwick, W.F. Fitchko, J., McKee, P.M., Hart, D.M., and Burt, A.J. 1987. The incidence of deformities in *Chironomus* spp. From Port Hope Harbour, Lake Ontario. Journal of Great Lakes Research 13: 88-92.**
Greater incidence of deformities in more heavily polluted interior vs. outer harbour.
Problem is that the polluted site is contaminated with radionuclies and metals.
Discussion cites a few studies of radionuclide doses and possible effects in other studies.

**Whicker, F. W., Pinder, J. E., III, Bowling, J. W., Alberts, J. J. and Brisbin, I. L., Jr. 1990. Distribution of long-lived radionuclides in an abandoned reactor cooling reservoir. Ecological Mongraphs 60: 471-496.**
PAR Pond - Cs, Sr, Pu, AM, Cm in water, sediments, fish, plants, birds, zooplankton.

**Whicker, F. W., Hinton, T. G., and Niquette, D. J. Effects of a partial drawdown on the dynamics of $^{137}$Cs in an abandoned reactor cooling reservoir. Pages 193-202 in Freshwater and Estuarine Radioecology, Demet, G., *et al.* (eds). Elsevier Science.**
Measured cesium activity in fish and sediments follwing PAR Pond drawdown.

| | | | |
|---|---|---|---|
| $^{137}$Cs | Aquatic plants in littoral zone | 2-29 | pCi/g dry |
| | Aquatic plants in exposed lake bed | up to 149 | pCi/g dry |
| | Largemouth bass | 16 | pCi/g wet |

**Whitmore, T.J. and Brenner, M. 1997. Historic water-quality assessment of Little Lake Jackson, Highlands County, Florida. Final report submitted to the Southwest Florida Water Management District, Brooksville, Florida.**
Two cores collected for dating sediments..

| | | | |
|---|---|---|---|
| $^{226}$Ra | Core 5 upper sample | 8.36 | dpm/g dry |
| | Core 6 upper sample | 9.38 | |

**Whitmore, T.J. and Brenner, M. 1999. Paleolimnological reconstruction of water quality in Lake Persimmon, Highlands County, Florida. Final report submitted to the Southwest Florida Water Management District, Brooksville, Florida.**
One core collected for dating sediments.

| | | | |
|---|---|---|---|
| $^{226}$Ra | upper sample | 11.6 | dpm/g dry |

**Wisconsin Department of Natural Resources. 2001. Summary of clamming regulations for Wisconsin waters. Web site: www.dnr.state.wi.us/org/water/fhp/fish/mussels.**
Clamming regulations identify takes of less than 50 lbs/day as non-comercial. Commercial liscence is required for greater harvests. Website gives information on "peaaling" and cooking of mussels.

**Wren, C. D., Cloutier, N. R, Lim, T. P., and Dave, N. K. 1987. Ra-226 concentrations in otter, *Lutra canadensis*, trapped near uranium tailings at Elliot Lake, Ontario. Bulletin of Environmental Contamination and Toxicology 38: 209-242.**
Radium-226 analysis of leg bones from six otters collected near Elliot Lake (uranium mine region) and one otter from Muskoka (control site). Radium detected in 5 of 7 samples from Elliot Lake, but not in 1 sample from control site.

| | | | | |
|---|---|---|---|---|
| $^{226}$Ra | Otter Femur | Elliot Lake area | nd-12.6 | pCi/g ash |
| | Otter Femur | Control site | | nd |

Citations of other results:

| | | | | |
|---|---|---|---|---|
| $^{226}$Ra | Meadow Vole Bone | Elliot Lake area | 52.3 (ave)pCi/g ash | |
| | | | | Cloutier et al. 1985 |
| | Spottail shiners | Saskatchewan | 70 (max) pCi/g ? | |
| | | | | Swanson 1983 |

Otters eat fish, clams, crayfish, some birds and small mammals. Typically eat slower, benthic feeding fish which according to Swanson have higher levels of radium.

"Clams and other benthic invertebrates have also been shown to accumulate significant levels of radionuclides (MOE 1978). Therefore, wildlife species such as otters, mink, and racoons, feeding on benthic aquatic organisms near tailing sites are potentially exposed to relatively high dietary Ra-226 levels."

# Exhibit 2

# U.S. Department of Energy
Washington, D.C.

# ORDER

DOE 5400.1

11-9-88

SUBJECT: GENERAL ENVIRONMENTAL PROTECTION PROGRAM

Chg 1: 6-29-90

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1. PURPOSE. To establish environmental protection program requirements, authorities, and responsibilities for Department of Energy (DOE) operations for assuring compliance with applicable Federal, State and local environmental protection laws and regulations, Executive orders, and internal Department policies. The Order more specifically defines environmental protection requirements that are generally established in DOE 5480. 1B.

2. SUPERSESSION. DOE 5480.1A, ENVIRONMENTAL PROTECTION, SAFETY, AND HEALTH PROTECTION PROGRAM FOR DOE OPERATIONS, of 8-13-81, Chapter XII, Prevention, Control, and Abatement of Environmental Pollution.

3. SCOPE. The provisions of this Order apply to all Departmental elements and contractors performing work for the Department as provided by law and/or contract as implemented by the appropriate contracting officer.

4. REFERENCES.

   d. DOE Orders.

      (1) DOE 4300.1B, REAL PROPERTY AND SITE DEVELOPMENT PLANNING, of 7-1-87, which establishes requirements for preparing site development plans for DOE facilities.

      (2) DOE 4700.1, PROJECT MANAGEMENT SYSTEM, of 3-6-87, which establishes requirements and objectives, and assigns responsibilities and authorities necessary for acquisition of major systems.

      (3) DOE 5000.3A, OCCURRENCE REPORTING AND PROCESSING OF OPERATIONS INFORMATION, of 5-30-90, which establishes a DOE system for identification, categorization, notification, analysis, reporting, followup, and closeout of occurrences.

      (4) DOE 5400.2A, ENVIRONMENTAL COMPLIANCE ISSUE COORDINATION, of 1-31-89, which sets forth policy, direction, and procedures for coordinating environmental issues that are of significance to DOE.

      (5) DOE Orders in the 5400 series dealing with radiation protection of the public and the environment.

Vertical line denotes change.

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DISTRIBUTION:
All Departmental Elements

INITIATED BY:
Assistant Secretary for Environment,
Safety, and Health

(6) DOE 5440.1C, NATIONAL ENVIRONMENTAL POLICY ACT, of 4-9-85, which establishes DOE policy for implementation of the National Environmental Policy Act of 1969.

(7) DOE 5480.1B, ENVIRONMENT, SAFETY, AND HEALTH PROGRAM FOR DEPARTMENT OF ENERGY OPERATIONS, of 9-23-86, which outlines environmental protection, safety, and health protection policies and responsibilities.

(8) DOE 5482.1B, ENVIRONMENT, SAFETY AND HEALTH APPRAISAL PROGRAM, of 9-23-86, which establishes the DOE environmental protection, safety, and health protection appraisal program.

(9) DOE 5484.1, ENVIRONMENTAL PROTECTION, SAFETY, AND HEALTH PROTECTION INFORMATION REPORTING REQUIREMENTS, of 2-24-81, which establishes the requirements and procedures for reporting and investigating matters of environmental protection, safety, and health protection significance to DOE operations.

(10) DOE 5500.1A, EMERGENCY MANAGEMENT SYSTEM, of 2-26-87, which establishes overall policies and requirements for DOE emergency preparedness and response programs.

(11) DOE 5700.6B, QUALITY ASSURANCE, of 9-23-86, which establishes DOE's quality assurance program.

(12) DOE 5820.2A, RADIOACTIVE WASTE MANAGEMENT of 9-26-88 which establishes policies and guidelines for the management of radioactive waste and contaminated facilities

(13) DOE 6430.1A, GENERAL DESIGN CRITERIA, of 4-6-89, which provides general design criteria for use in acquisition of DOE facilities.

b. Legislation.

(1) Title 42 U.S.C. 2011, et seq., The Atomic Energy Act of 1954, as amended, which authorizes the conduct of atomic energy activities.

(2) Title 42 U.S.C. 7101, et seq., The Department of Energy Organization Act, which establishes the statutory responsibility to ensure incorporation of national environmental protection goals in the formulation of energy programs, and advance the goal of restoring, protection, and enhancing environmental quality, and assuring public health and safety.

Vertical line denotes change.

Exhibit 3

# U.S. Department of Energy
## Washington, D.C.

# ORDER

DOE 5400.5

2-8-90

Change 2: 1-7-93

**SUBJECT:** RADIATION PROTECTION OF THE PUBLIC AND THE ENVIRONMENT

---

1. PURPOSE. To establish standards and requirements for operations of the Department of Energy (DOE) and DOE contractors with respect to protection of members of the public and the environment against undue risk from radiation.

2. SUPERSESSION. DOE 5480.1A, ENVIRONMENTAL PROTECTION, SAFETY, AND HEALTH PROGRAM FOR DOE OPERATIONS, of 8-13-81, Chapter XI that addressed public and environmental radiation protection standards and control practices.

3. SCOPE. The provisions of this Order apply to all Departmental Elements and contractors performing work for the Department as provided by law and/or contract and as implemented by the appropriate contracting officer.

4. IMPLEMENTING PROCEDURES AND REQUIREMENTS. This Order becomes effective 5-8-90. Within 2 months from the date of issuance of the Order (2-8-90), the DOE Field Office Manager shall provide to the appropriate Program Office, with a copy to EH-1 for review and comment: a. a certification for those areas covered by the Order for which field elements are in compliance; and/or b. a request for exemption for areas not yet in compliance that includes a Plan for achieving compliance. Within 3 months of issuance, the appropriate Program Office will submit to EH-1 the certification and/or the request for exemption(s). The compliance plan accompanying the request for exemption shall include schedules of activities which will lead to compliance with the requirements of this Order.

5. POLICY. It is the policy of DOE to implement legally applicable radiation protection standards and to consider and adopt, as appropriate, recommendations by authoritative organizations, e.g., the National Council on Radiation Protection and Measurements (NCRP) and the International Commission on Radiological Protection (ICRP). It is also the policy of DOE to adopt and implement standards generally consistent with those of the Nuclear Regulatory Commission (NRC) for DOE facilities and activities not subject to licensing authority.

6. OBJECTIVES.

   a. Protecting the Public. It is DOE's objective to operate its facilities and conduct its activities so that radiation exposures to members of the public are maintained within the limits established in this Order and to control radioactive contamination through the management of real and personal property. It is also a DOE objective that potential exposures to members of the public be as far below the limits as is reasonably achievable (ALARA) and that DOE facilities have the capabilities, consistent with the types of operations conducted, to monitor routine and non-routine releases and to assess doses to members of the public.

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**INITIATED BY:**
Office of Environment, Safety and Health

Vertical line denotes change.

b. Protecting the Environment. In addition to providing protection to members of the public, it is DOE'S objective to protect the environment from radioactive contamination to the extent practical.

7. LEGISLATIVE AUTHORITY. The Atomic Energy Act of 1954, as amended, authorizes the Department to protect the health and safety of the public against radiation in conducting the Department's programs.

8. REFERENCES.

a. DOE 1324.2A, RECORDS DISPOSITION, of 9-13-88, which prescribes policies, procedures, standards, and guidelines for the orderly disposition of records of the DOE and its operating contractors.

b. DOE 5000.3B, OCCURRENCE REPORTING AND PROCESSING OF OPERATIONS INFORMATION, of 1-19-93, which establishes a system for reporting operations information related to DOE-owned or operated facilities and processing of the information.

c. DOE 5400.1, GENERAL ENVIRONMENTAL PROTECTION PROGRAM REQUIREMENTS, of 11-9-88, which establishes general environmental protection requirements.

d. DOE 5400.2A, ENVIRONMENTAL COMPLIANCE ISSUE COORDINATION, of 1-31-89, which establishes requirements for coordination of significant environmental compliance issues.

e. DOE 5400.4, COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION, AND LIABILITY ACT PROGRAM, of 10-6-89, which establishes requirements for hazardous waste cleanup and notification.

f. DOE 5440.1E, NATIONAL ENVIRONMENTAL POLICY ACT COMPLIANCE PROGRAM, of 11-10-92, which establishes DOE policy for implementation of the National Environmental Policy Act of 1969.

g. DOE 5480.1B, ENVIRONMENT, SAFETY, AND HEALTH PROGRAM FOR DEPARTMENT OF ENERGY OPERATIONS, of 9-23-86, which outlines environmental, safety, and health protection policies and responsibilities.

h. DOE 5480.4, ENVIRONMENTAL PROTECTION, SAFETY, AND HEALTH PROTECTION STANDARDS, of 5-15-84, which identifies mandatory and reference environmental, safety, and health standards.

i. DOE 5480.5, SAFETY OF NUCLEAR FACILITIES, of 9-23-86, which establishes nuclear facility safety program requirements.

j. DOE 5480.6, SAFETY OF DEPARTMENT OF ENERGY-OWNED NUCLEAR REACTORS, of 9-23-86, which establishes nuclear reactor safety program requirements.

(2) Discharge at Less Than DCG Level. Implementation of the BAT process for liquid radioactive wastes is not required where radionuclides are already at a low level, i.e., the annual average concentration is less than DCG level. In that case, the cost consideration component of BAT analysis precludes the need for additional treatment, since any additional treatment would be unjustifiable on a cost-benefit basis. Therefore, additional treatment will not be required for waste streams that contain radionuclide concentrations of not more than the DCG values in Chapter III at the point of discharge to a surface waterway. However, the ALARA provisions are applicable.

(3) Multiple Radionuclides. For purposes of II.3a(1), above, the DCG for liquid waste streams containing more than one type of radionuclide shall be the sum of the fractional DCG values.

(4) Sedimentation. To prevent the buildup of radionuclide concentrations in sediments, liquid process waste streams containing radioactive material in the form of settleable solids may be released to natural waterways if the concentration of radioactive material in the solids present in the waste stream does not exceed 5 pCi (0.2 Bq) per gram above background level, of settleable solids for alpha-emitting radionuclides or 50 pCi (2 Bq) per gram above background level, of settleable solids for beta-gamma-emitting radionuclides.

(5) Interim Dose Limit for Native Aquatic Animal Organisms. To protect native animal aquatic organisms, the absorbed dose to these organisms shall not exceed 1 rad per day from exposure to the radioactive material in liquid wastes discharged to natural waterways. DOE publication DOE/EH-0173T provides guidance on monitoring and calculating dose for aquatic organisms.

(6) New Facilities. New facilities shall be designed and constructed to meet the discharge requirements shown in paragraph II.3a.

b. Discharges of Liquid Waste to Aquifers and Phaseout of Soil Columns.

(1) Phasing Out the Use of Soil Columns. The use of soil columns (i.e., trenches, cribs, ponds, and drain fields) to retain, by sorption or ion exchange, suspended or dissolved radionuclides from liquid waste streams shall be discontinued at the earliest practicable time in favor of an acceptable alternative disposal means. DOE activities that currently discharge liquids containing radioactive materials not first treated by BAT to soil columns, shall develop, within 6 months of the issuance date of this Order, a plan and schedule for implementing alternate acceptable disposal at the earliest practicable time. The BAT selection process shall be applied to those liquid waste streams that will continue to be discharged to soil columns for indefinite periods and which contain process-derived radionuclides. The plan shall be submitted for approval

# Exhibit 4

ES/ER/TM-78

# Methodology for Estimating Radiation Dose Rates to Freshwater Biota Exposed to Radionuclides in the Environment

B. G. Blaylock
M. L. Frank
B. R. O'Neal

ES/ER/TM-78

# Methodology for Estimating Radiation Dose Rates to Freshwater Biota Exposed to Radionuclides in the Environment

B. G. Blaylock
M. L. Frank
B. R. O'Neal

Date Issued—September 1993

Prepared for the
U.S. Department of Energy
Office of Environmental Management
under budget and reporting code EW 20

LOCKHEED MARTIN ENERGY SYSTEMS, INC.
managing the
Environmental Management Activities at the
Oak Ridge K-25 Site  Paducah Gaseous Diffusion Plant
Oak Ridge Y-12 Plant  Portsmouth Gaseous Diffusion Plant
Oak Ridge National Laboratory
under contract DE-AC05-84OR21400
for the
U.S. DEPARTMENT OF ENERGY

# CONTENTS

# EXECUTIVE SUMMARY

The purpose of this report is to present a methodology for evaluating the potential for aquatic biota to incur effects from exposure to chronic low-level radiation in the environment. Aquatic organisms inhabiting an environment contaminated with radioactivity receive external radiation from radionuclides in water, sediment, and from other biota such as vegetation. Aquatic organisms receive internal radiation from radionuclides ingested via food and water and, in some cases, from radionuclides absorbed through the skin and respiratory organs. Dose rate equations, which have been developed previously, are presented for estimating the radiation dose rate to representative aquatic organisms from alpha, beta, and gamma irradiation from external and internal sources. Tables containing parameter values for calculating radiation doses from selected alpha, beta, and gamma emitters are presented in the appendix to facilitate dose rate calculations.

The risk of detrimental effects to aquatic biota from radiation exposure is evaluated by comparing the calculated radiation dose rate to biota to the U.S. Department of Energy's (DOE's) recommended dose rate limit of 0.4 mGy $h^{-1}$ (1 rad $d^{-1}$). A dose rate no greater than 0.4 mGy $h^{-1}$ to the most sensitive organisms should ensure the protection of populations of aquatic organisms. DOE's recommended dose rate is based on a number of published reviews on the effects of radiation on aquatic organisms that are summarized in the National Council on Radiation Protection and Measurements Report No. 109 (NCRP 1991). The literature identifies the developing eggs and young of some species of teleost fish as the most radiosensitive organisms. DOE recommends that if the results of radiological models or dosimetric measurements indicate that a radiation dose rate of 0.1 mGy $h^{-1}$ will be exceeded, then a more detailed evaluation of the potential ecological consequences of radiation exposure to endemic populations should be conducted.

Dose rates have been calculated for biota in aquatic ecosystems associated with three national laboratories and one uranium mining and milling facility (NCRP 1991). At all sites, the dose rates were two orders of magnitude less than the value recommended by DOE for the protection of populations of aquatic biota. Therefore, it is highly unlikely that aquatic organisms will encounter dose rates in aquatic ecosystems that will be detrimental at the population level other than in man-made bodies of water associated with waste management activities or from accidental releases of radionuclides.

# 1. INTRODUCTION

Sources of radioactivity in the aquatic environment include naturally occurring radionuclides, fallout from the atmospheric, runoff from watersheds that have received atmospheric deposition, and radioactive effluents from medical, industrial, and nuclear facilities released either accidentally or routinely. Depending upon the element and the chemical form, radionuclides may accumulate in bottom sediment or remain in the water column in the dissolved state. From either location, they can subsequently accumulate in biota and be transferred through the aquatic food chain. Contamination of the environment by radionuclides inevitably results in an increase in the radiation exposure of natural populations of organisms that occupy the contaminated area. Aquatic organisms receive external radiation exposure from radionuclides in water, sediment, and from other biota such as vegetation. They also receive internal radiation exposure from radionuclides ingested via food and water and from radionuclides absorbed through the skin and respiratory organs.

Generally, the discharge of radioactive waste into the environment is such that it results in only long-term, low-dose-rate exposure of organisms. In most cases, acute mortality can be discounted. The very small increase in morbidity and mortality that is contributed by an increased exposure to chronic irradiation is unlikely to be detectable because of the natural fluctuations in the sizes of populations of organisms in the aquatic environment. The purpose of this report is to present a methodology for evaluating the ecological risk to aquatic organisms that are exposed to anthropogenic radionuclides released into the environment.

# 2. APPROACH

Ecological risk to aquatic organisms exposed to radiation from anthropogenic radionuclides in the environment will be assessed by 1) calculating the dose to the organism and 2) comparing that dose to levels of radiation below which no detectable effects have been observed. Special consideration will be given to effects on reproductive parameters such as fecundity and embryo viability which would be the most likely to be adversely affected by exposure to radiation.

Although most radiation effect studies have evaluated effects at the organism level, assessments of ecological risk are usually concerned with the viability and success of populations. Unlike the case for humans in which malignancies and genetic abnormalities can be a personal catastrophe, there usually is not a similar concern about the survival of individual organisms in nature. An exception exists for threatened or endangered species or species with low fecundity (typically uncommon in freshwater ecosystems), where the survival of an individual could influence the success of the population. In most cases, the potential for over-reproduction of aquatic organisms is large and most individuals either become part of the natural food chain to be consumed by other organisms or starve. Therefore, for aquatic organisms there is little concern about small increases in the frequency of malignancies or genetic abnormalities because the weakest individuals are usually eliminated first in the natural selection process.

## 3. EFFECTS OF RADIATION ON AQUATIC ORGANISMS

A large body of literature exists on the effects of radiation on aquatic organisms and has been reviewed extensively by a number of authors (IAEA 1976; Blaylock and Trabalka 1978; NRCC 1983; Egami and Ijiri 1979; Woodhead 1984; Anderson and Harrison 1986; NCRP 1991). The general consensus of the reviewers is that the most sensitive aquatic organisms known are teleost fish, particularly the developing eggs and young of some species. Additionally, the reviewers point out that most radiation effects studies have been conducted using acute exposures of radiation and less than 10% of the studies involved chronic or continuous irradiation. Because most environmental exposures are long-term, low-dose-rate exposures, data from chronic irradiation effect studies on the life cycle of organisms are the most useful in assessing the ecological risk to biota.

One approach that is used in assessing the risk of adverse ecological effects is to select indicator species of organisms for study. Indicator species are usually biologically significant organisms and are representative of the particular environment under investigation. An assessment of the environment will usually allow the identification of a few critical species of organisms for which dose estimates should be made. These species should provide adequate data for an assessment of effects from the radiation exposure to the community.

## 4. RADIATION DOSE TO BIOTA

Three approaches have been employed for calculating radiation doses to aquatic biota. Results of using these three approaches were evaluated by Woodhead (NCRP 1991). CRITR, a set of models and associated computer codes, was developed by Soldat et al. (1974) and recently revised by Baker and Soldat (1992) for application to discharges of effluents into surface waters. A simplified means was provided for calculating the concentrations of radionuclides in water, sediment, and two groups of organisms using a restricted number of parameters relating to the discharge source and the receiving water body.

A second approach involved two models, EXREM III and BIORAD (Trubey and Kaye 1973), which were developed from the starting point of a unit concentration of a radionuclide in water from which the concentration in an organism is determined by the application of a concentration factor. No means are given for estimating the concentration of a radionuclide in sediment or determining the exposure from contaminated sediment which may be significant.

A third approach, "Point Source Dose Distribution" (IAEA 1976, 1979), is advantageous in that it can be applied to any combination of radiation sources and target geometries. For any extended (nonpoint) source of ionizing radiation, the dose rate at a specified point can be obtained by the integration of an appropriate point source dose function over the source geometry. Although it is possible to derive theoretical expressions from first principles, these calculations are frequently complex due to the multiplicity of absorption and scattering phenomena which must be considered. For ease of computation, simple empirical expressions have been described for calculating doses to aquatic biota (IAEA 1976, 1979).

Several factors makes estimating the radiation dose to an organism difficult. Different radionuclides are differentially distributed among the organs and tissues of an organism, affecting the radiation dose that sensitive organs and tissues receive. In addition, the relative significance of internal and external sources of radiation to an organism can be markedly altered by the size and behavior of the organism.

Radiation exposure models have been developed that incorporate parameters accounting for differences in the size and shape of an organism. The "Point Source Dose Distribution" methodology provides a means for calculating the radiation dose to different size categories of aquatic organisms using simplified equations. Measurements used to represent different size categories for a select group of aquatic organisms are given in Table 1.

**Table 1. Dimensions of organisms representing different size categories used in the Point Source Dose Distribution methodology for estimating radiation doses**

| Organism | Mass (kg) | Length of the major axes of the ellipsoid (cm) |
|---|---|---|
| Small insects and larvae | $1.6 \times 10^{-5}$ | 0.62 x 0.31 x.0.16 |
| Large insects and molluscs | $1.0 \times 10^{-3}$ | 2.5 x 1.2 x 0.62 |
| Small fish | $2.0 \times 10^{-3}$ | 3.1 x 1.6 x 0.78 |
| Large fish | 1.0 | 45 x 8.7 x 4.9 |

## 4.1 □-radiation

For large organisms with dimensions greater than a few cm, energy absorption and scattering become significant; therefore, a factor must be applied to account for these processes. Monte Carlo calculations have been made to include absorption and scattering for a number of geometries, and these calculations can be adapted for aquatic organisms (Brownell et al. 1968, Ellett and Humes 1971). The results are given in terms of the absorbed fraction which is defined as:

$$\square = \frac{\text{photon energy absorbed by target}}{\text{photon energy emitted by source}}$$

Absorbed fractions (□ ) which have been derived for the biota listed in Table 1 as a function of □-ray energies (ICRP 1991) are given in Figures A.1 through A.3.

The □-radiation dose rate from internal contamination is expressed as:

$$D_{\square} = 5.76 \text{ x } 10^{-4}\, E_{\square}\, n_{\square}\, \square \;\; C_o \qquad \mu\text{Gy h}^{-1} \qquad (1)$$

where

$E_{\square}$ is the photon energy emitted during transition from a higher to a lower energy state (MeV)
$n_{\square}$ is the proportion of disintegrations producing a □-ray
□ is the absorbed fraction from Figures A.1 through A.3 of energy $E_{\square}$ (MeV) (dimensionless)
$C_o$ is the concentration of the radionuclide in the organism (Bq kg$^{-1}$ wet weight)

If a □-emitter produces photons of different energy levels, the doses from all major □-emissions should be included in the dose rate calculation.

It follows that the □-radiation dose rate to the organism from radionuclides in water away from the sediment is

$$D_{\square}= 5.76 \text{ x } 10^{-4}\, E_{\square}\, n_{\square}(1-\square\,)C_w \qquad \mu\text{Gy h}^{-1} \qquad (2)$$

where

$C_w$ is the concentration of the radionuclide in water (Bq L$^{-1}$)

The □-radiation dose rate to organisms at the sediment-water interface from a uniformly contaminated sediment is

$$D_{\square}= 2.88 \text{ x } 10^{-4}\, E_{\square}\, n_{\square}(1-\square\,)\; C_s R \qquad \mu\text{Gy h}^{-1} \qquad (3)$$

where

$C_s$ is the concentration of the radionuclide in sediment (Bq kg$^{-1}$ wet weight). A generic value of 0.75 can be used for converting sediment from dry weight to wet weight.
R is the fraction of time that the organism spends at the sediment-water interface.

Because of deposition and resuspension of sediment, decay of the radioisotope, and the variability in the rate at which a radionuclide may be released into a aquatic system, sediment rarely presents a uniform, semi-infinite source of □-radiation. Therefore, in most cases, equation (3) will over estimate the dose to biota at the sediment-surface water interface. In those cases where detailed information is not available, 0.5 times the $D_{\square}$ in equation (3) can be used to account for the unequal distribution of radionuclides in the sediment (IAEA 1976, Woodhead 1984).

Table A.1 contains the average energy per transformation for a selected group of gamma emitters. These values were taken from ICRP Report 38 (1983) and can be used in place of $E_{\square}$ and $n_{\square}$ in the preceding equations to calculate the total □-radiation dose rate in one step. Examples illustrating the calculation of □-radiation dose rates are given in Appendix B.

## 4.2 □-radiation

The point source □-dose function (NCRP 1991, Woodhead 1979) was integrated over the geometries given in Table 1, assuming a uniform distribution of the radionuclide in the organism, to obtain the dose rate at the center of the organism as a fraction of the total □-dose rate. The results are shown in Fig. A.4 as a function of maximum □-particle energy for the three small geometries. For large fish and turtles, the internal □-dose rate is independent of the □-particle energy; therefore,

$$D_{\square} = 5.76 \times 10^{-4}\ \square_{\square}\, n_{\square}\, C_o \qquad \mu Gy\ h^{-1} \qquad (4)$$

The internal □-radiation dose rate for the three small geometries is given by the following equation

$$D_{\square} = 5.76 \times 10^{-4}\ \square_{\square}\, n_{\square}\, \square\ C_o \qquad \mu Gy\ h^{-1} \qquad (5)$$

where

$\square_{\square}$ is the average energy of the □-particle (MeV)

$n_{\square}$ is the proportion of transitions producing a □-particle of energy $E_{\square}$ (MeV) (dimensionless)

□ is the absorbed fraction from Fig. A.4

$C_o$ is the concentration of the radionuclide in the organism (Bq kg$^{-1}$ wet weight)

It is assumed that □-radiation from water contributes a negligible amount to the internal dose rate of large fish and turtles. The external □-dose rate from water for the smaller organisms described in Table 1 is

$$D_{\square} = 5.76 \times 10^{-4}\ \square_{\square}\, n_{\square}\, (1-\square)\ C_w \qquad \mu Gy\ h^{-1}. \qquad (6)$$

where

$C_w$ is the concentration of the radionuclide in water (Bq L$^{-1}$)

The external □-dose rate from sediment for organisms represented by the three small geometries that are in contact with the sediment surface is

$$D_{\square} = 2.88 \times 10^{-4}\ \square_{\square}\, n_{\square}\, (1-\square)\, C_s R \qquad \mu Gy\ h^{-1}. \qquad (7)$$

where

$C_s$ is the concentration of the radionuclide in sediment (Bq kg$^{-1}$ wet weight). A generic value of 0.75 can be used for converting sediment from dry weight to wet weight.

R is the fraction of time that the organism spends at the sediment-water interface.

Some aquatic organisms may be surrounded by sediment during certain life stages and, in such cases, $5.76 \times 10^{-4}$ instead of $2.88 \times 10^{-4}$ would be the appropriate unit conversion factor.

Beta emitters that decay by alternative transitions produce an energy spectrum for each mode of transition. The dose rates from the major spectra must be included when calculating the total □-dose rate to an organism. Table A.1 contains a list of the maximum and average energies of selected □-emitters based on □-particles, conversion electrons, and Auger radiations. These values were obtained from ICRP Report 38 (1983). Examples demonstrating the use of the data in Table A.1 to calculate □-dose rates are given in Appendix B.

## 4.3 □-radiation

For organisms of the sizes represented in Table 1, the internal dose rate from □-radiation closely approaches the dose rate from an infinite source because essentially all the energy from □-particles is absorbed within the organism. The internal dose rate from □-radiation is calculated as follows:

$$D_{\square} = 5.76 \times 10^{-4} E_{\square} n_{\square} C_o \qquad \mu\text{Gy h}^{-1} \qquad (8)$$

where

$E_{\square}$ is the energy of the □-particle (MeV)

$n_{\square}$ is the proportion of transitions producing an □-particle of energy $E_{\square}$(MeV) (dimensionless)

$C_o$ is the concentration of the radionuclide in the organism (Bq $\text{kg}^{-1}$ wet weight)

If □-particles of more than one energy level are produced during the decay of a radioisotope, the dose rate from all transitions are summed to obtain the total a-dose rate. It is assumed that external □-radiation from water and sediment is insignificant for organisms of the sizes shown in Table 1.

Table A.2 gives the average □-energies for selected □-emitters including those in naturally occurring □-decay chains. The average energy of □- and □-emissions produced by the □-decay are also given. Examples illustrating the calculation of dose rates for a-emitters are presented in Appendix B.

The dose rates in this report are expressed in units of absorbed dose (μGy); however, different types of radiations differ in their relative biological effectiveness per unit of absorbed dose. A quality factor, Q, is normally used to account for the difference in biological effectiveness of the different radiations (NCRP 1987). Quality factors have been derived from data on humans and are intended to be used only for low doses, not high doses that might result from a nuclear accident. A quality factor of 1 is used for x-, □-, and □-radiation and 20 for □-radiation. Therefore, to equate the relative biological effectiveness of the dose rate from □-radiation in μGy to the rate from □- and □-

radiations, the □-dose rate should be multiplied by 20. In effect, the resulting dose rate would be equivalent to microsieverts (μSv), the dose equivalent unit used for humans.

## 5. DOSE RATE CALCULATIONS FOR FISH EGGS

The calculation of a radiation dose to fish eggs/embryos exposed to radionuclides in the environment is a complex procedure that requires answers to a number of questions. These questions include: Is the radionuclide inside the egg or is it adsorbed to the outer shell or chorion? If the radionuclide is inside the egg, is it uniformly distributed? What is the diameter of the egg? Where is the developing embryo located? Do the eggs float, sink to the bottom, form clusters, adhere to vegetation or other objects, etc.? How long is the development period and does the radionuclide concentration change with time? If answers to these questions are available, it is possible to use mathematical models for different geometries and physical conditions to calculate the radiation dose rate to fish eggs/embryos (Adams 1968, Woodhead 1970, Ellett and Humes 1971, IAEA 1979). However, for most purposes a conservative estimate of the radiation dose rate is sufficient. The following discussion presents a simplified approach for estimating the dose rate to fish eggs/embryos from radionuclides in the environment.

### □-radiation to Fish Eggs

Most fish eggs are only a few millimeters in diameter; therefore, the radiation dose rate from internal □-emitters would be insignificant (Ellett and Humes 1971, IAEA 1976). The external dose rate to an egg from □-emitters in the surrounding water would be the average dose rate in an effectively infinite source (i.e., the dimensions of the source are much greater than the attenuation length of the radiation). The unit density of the fish eggs and the source (water) are assumed to be the same. The equation for the □-dose rate from an infinite source is

$$D_{\square}(\square)= 5.76 \times 10^{-4} E_{\square}\ n_{\square}\ C_{w} \qquad \mu\mathrm{Gy\ h^{-1}} \quad (9)$$

where

$E_{\square}$ is the photon energy emitted during transition from a higher to a lower energy state (MeV)

$n_{\square}$ is the proportion of disintegrations producing a □-ray of energy $E_{\square}$ (MeV) (dimensionless)

$C_w$ is the concentration of the radionuclide in water (Bq $L^{-1}$)

Because the activity of most radionuclides in water is much lower than in biological tissue and because eggs of most species of freshwater fish hatch in a few weeks or less, it is unlikely that the radiation dose from □-emitters in the environment would have a deleterious effect on fish eggs/embryos.

Fish eggs may receive external □-radiation from other sources such as sediment and vegetation and a number of geometric factors would affect the dose rate. For most radionuclides, the activity in the sediment is much higher than in the water, so that the dose rate from the sediment will be higher than from the water. However, the dose rate to fish eggs would depend upon the photon energy and their distance from the sediment surface. Assuming that the sediment is a uniformly contaminated slab source of infinite area and the eggs are lying on the sediment surface, the following equation can be used to estimate the □-dose rate to the eggs.

$$D_{\square}(\square) = 2.88 \times 10^{-4}\, E_{\square}\, n_{\square}\, C_s \qquad \mu\text{Gy h}^{-1} \qquad (10)$$

where

$E_{\square}$ is the photon energy emitted during transition from a higher to a lower energy state (MeV)

$n_{\square}$ is the proportion of disintegrations producing a □-ray of energy $E_{\square}$ (MeV) (dimensionless)

$C_s$ is the concentration of the radionuclide in sediment(Bq kg$^{-1}$ wet weight). A generic value of 0.75 can be used for converting sediment from dry weight to wet weight.

### □-radiation to Fish Eggs

Equations for calculating the dose rate to fish eggs from internal □-emitters are complex and beyond the scope of this report. By assuming that all the energy from internal □-emitters is absorbed within the egg, the following equation can be used to estimate the dose.

$$D_{\square} = 5.76 \times 10^{-4}\, \square_{\square}\, n_{\square}\, C_o \qquad \mu\text{Gy h}^{-1} \qquad (11)$$

where

$\square_{\square}$ is the average energy of the □-particle (MeV)

$n_{\square}$ is the proportion of transitions producing a □-particle of energy $\square_{\square}$ (MeV) (dimensionless)

$C_o$ is the concentration of the radionuclide in the organism (□q kg$^{-1}$ wet weight)

Results of equation (11) are approximately true for low-energy □-radiation; however, as the □-particle energy increases, the extent of over estimation increases. If the estimated dose rate indicates that harmful effects might occur, then a more accurate dose rate should be determined. Equations for calculating dose rates to fish eggs are available in the literature (IAEA 1979, Adams 1968, and Woodhead 1970).

If the range of the □-radiation in the surrounding water exceeds the radius of the eggs, then the dose rate to the eggs from the water is

$$D_{\square} = 5.76 \times 10^{-4}\, \square_{\square}\, n_{\square}\, C_w \qquad \mu\text{Gy h}^{-1} \qquad (12)$$

where

$\square_{\square}$ is the average energy of the □-particle (MeV)

$n_{\square}$ is the proportion of transitions producing a □-particle of energy $\square_{\square}$ (MeV) (dimensionless)

$C_w$ is the concentration of the radionuclide in water (Bq L$^{-1}$)

Equation (12) can be used to estimate the □-dose rate from water in instances where the range of the □-particle is less than the radius of the egg but the dose rate will be over estimated. As mentioned above, if the estimated dose rate indicates harmful effects might occur, then a more accurate estimate of the dose rate should be obtained.

Fish eggs can also receive □-radiation from contact with surfaces such as sediment or vegetation. The dose rate will depend upon the thickness and density of the material as well as the energy of the □-radiation. The following equation can be used to estimate to dose to eggs that are in contact with sediment although in most situations it will over estimate the dose rate.

$$D_{\square} = 2.88 \times 10^{-4}\, \square_{\square}\, n_{\square}\, C_s R \qquad \mu Gy\ h^{-1}. \qquad (13)$$

where

$C_s$ is the concentration of the radionuclide in sediment (Bq kg$^{-1}$ wet weight). A generic value of 0.75 can be used for converting sediment from dry weight to wet weight

R is the fraction of time that the organism spends at the sediment-water interface.

**□-radiation to Fish Eggs**

Assuming that all the radiation from internal □-emitters remains within the egg and that all external □-radiation is stopped by the chorion, a reasonable estimate of the dose rate from □-emitters is given by

$$D_{\square} = 5.76 \times 10^{-4}\, E_{\square}\, n_{\square}\, C_o \qquad \mu Gy\ h^{-1} \qquad (14)$$

where

$E_{\square}$ is the energy of the □-particle (MeV)

$n_{\square}$ is the proportion of transitions producing an □-particle of energy $E_{\square}$ (MeV) (dimensionless)

$C_o$ is the concentration of the radionuclide in the organism (Bq kg$^{-1}$ wet weight)

## 6. DOSE CALCULATIONS AND EFFECTS

The previously listed equations can be used to calculate a dose rate to aquatic biota for most situations. Bioaccumulation factors for freshwater fish for selected radioisotopes are included in Tables A.1 and A.2. These factors can be used to estimate the concentration of a radioisotope in freshwater fish from the concentration in the surrounding water. Information on the decay schemes of additional radioisotopes can be obtained from ICRP 38 (ICRP 1983), Kocher (1981), and the Health Physics and Radiological Health Handbook (Shleien et al. 1984). Equations for calculating dose rates for other biota, such as fish eggs, phytoplankton, and zooplankton, can be found in IAEA Technical Reports Series No. 172 (1976) and Series No. 190 (1979). After determining the dose rate to an organism from each individual radioisotope in the environment, the total dose rate to the organism is determined by summing the dose rates (in dose equivalents) from all radioisotopes. The total dose rate can then be compared to literature values for radiation effects on the same or closely related organisms. The most appropriate values for comparison are those from chronic exposure studies conducted over the life cycle of an organism; however, it is often necessary to extrapolate the results of acute exposures to chronic exposures.

A number of reviews on the effects of radiation on aquatic organisms have been published over the last three decades (Polikarpov 1966, Templeton et al. 1971, Chipman 1972, IAEA 1976, Blaylock and Trabalka 1978, IAEA 1979, Egami 1980, NRCC 1983, Woodhead 1984, Anderson and Harrison 1986, NCRP 1991, and IAEA 1992). These reviews considered data from field and laboratory studies from both marine and freshwater environments. More data have been collected on marine than on freshwater species; however, where reasonable comparisons can be made, there is no evidence that significance differences in radiosensitivity exists between marine and freshwater organisms. NCRP Report No. 109 (NCRP 1991) contains summary tables of the effects of chronic irradiation on fish and invertebrates. Tables A.3 through A.6 are modifications of the NCRP tables. For information on specific organisms not contained in these tables, individual reviews can be consulted, for example, Woodhead (1984).

Methods for dose calculations for phytoplankton and zooplankton are not included in this document because these organisms are relatively resistant to irradiation exposure (Table A.5) (Marshall 1962, 1966). From reviews of the literature (IAEA 1976; Blaylock and Trabalka 1978; Woodhead 1984), detrimental effects on organisms of higher trophic levels should be detected before populations of phytoplankton and zooplankton are affected by exposure to radiation. Therefore, dose calculations for organisms of higher trophic levels are emphasized in this report. The methodology for calculating dose rates for phytoplankton and zooplankton is available in the IAEA Technical Report 172 (1976).

The U.S. Department of Energy's (DOE) guideline for radiation dose rates from environmental sources, which recommends limiting the radiation dose to aquatic biota to 0.4 mGy $h^{-1}$ (1 rad $day^{-1}$), is based on results of previously cited reviews summarized in NCRP Report No. 109 (NCRP 1991). The conclusion from these reviews is that at 0.4 mGy $h^{-1}$, there is no evidence that deleterious effects have been expressed at the population level for aquatic biota. Tables A.3 through A.5 contain summaries from the literature reviewed in NCRP Report No. 109 on reproductive effects in fish exposed to chronic irradiation. In these chronic irradiation studies, effects were not detected unless the dose rates were much greater than 0.4 mGy $h^{-1}$. However, populations may be at risk from other factors, such as over exploitation or other environmental stresses, which might in combination with radiation have an undesirable impact. Therefore, it is desirable to conduct a comprehensive ecological evaluation of the radiation exposure regime in combination with other environmental factors in order to assess the potential for radiation contributing to effects at the population level. It is recommended (NCRP 1991) that where the results of radiological models or dosimetric measurements indicate a dose rate of 0.1 mGy $h^{-1}$ or more to aquatic biota, a more detailed evaluation of the ecological consequences to the endemic biota should be conducted.

According to the radiation effects literature, the most radiosensitive aquatic organisms are the developing eggs and young of some species of teleost fish. With few exceptions, the developmental period for freshwater fish eggs is relatively short but it can range from 3 days for the common carp *Cyprinous carpio* to more than 70 days for some salmonidae species. For this reason, the accumulated radiation dose to fish eggs from chronic environmental radiation should be relatively small. It is highly unlikely that dose rates in natural aquatic ecosystems that receive routine releases of radioactive effluents would produce effects on developing eggs and young of fish that would influence the success of the population. Exceptions to this premise could occur as a result of accidental releases of unacceptable levels of radioactive effluents or in man-made waste disposal ponds where high concentrations of radionuclides may be present.

In NCRP Report No. 109 (NCRP 1991), dose rates to aquatic organisms were calculated for three DOE-operated sites and one site in Canada: Gable Mountain Pond, Hanford Plant, Washington; White Oak Lake, Oak Ridge National Laboratory, Tennessee; Savannah River Plant, South Carolina; and Beaverlodge Uranium Mining Area, Saskatchewan, Canada. The estimated whole-body doses received by aquatic organisms at these sites were more than two orders of magnitude below the proposed standard of 0.4 mGy $h^{-1}$. However, a few dose rates approached 0.1 mGy $h^{-1}$, which might in combination with environmental stresses have an undesirable impact. The highest dose rates occurred in man-made ponds associated with waste management activities and these ponds have no direct connection with natural bodies of water. Remedial actions have been implemented at these sites. Therefore, it is highly unlikely that environmental situations will be encountered where the risk from radiation exposure from releases of radioactive waste to the environment would produce detrimental effects on aquatic organisms at the population level.

The methodology for calculating conservative (upper-limit) radiation dose rates provided in this document can be used to estimate dose rates to biota inhabiting aquatic environments contaminated with radionuclides. If the dose rate to aquatic organisms is less than the DOE's recommended level of 0.4 mGy $h-^{1}$ (1 rad $day^{-1}$), there should be no detrimental effects from radiation exposure at the population level, i.e., there should be no quantifiable risk to the biota. If estimated dose rates exceed 0.1 mGy $h^{-1}$, then studies should be implemented to determine whether effects can be detected at the individual and/or population level for biota inhabiting the environment.

Exhibit 5

# ILLINOIS ENDANGERED AND THREATENED SPECIES

# RIVER OTTER

*Lutra canadensis*

## ENDANGERED

**Class: Mammalia** **Order: Carnivora** **Family: Mustelidae**

### Description

The river otter is a member of the weasel family, which includes such familiar species as mink, badger, and skunk. Highly adapted to aquatic life, the otter's long streamlined body and powerful tapered tail enable it to swim and move with strength and speed. Short, strong legs and fully webbed feet further enhance its swimming ability. Its head is relatively small, broad and flat, with small ears that are closed when underwater, a large nose pad, and stiff, sensitive whiskers which help it to detect food underwater. The otter's eyes are small and located high on its head, which allows it to swim low in the water with only the top of its head above the surface. Its short, thick fur is a rich brown color and serves as an insulating layer by trapping air when the animal is submerged. The otter's ability to conserve oxygen allows it to stay underwater for 4 minutes at a time. Adult otters may be as much as four feet in length, with the tail accounting for nearly a third of their total length. Their weight averages 15 pounds among adult females, and may be 25 pounds for an adult male.

### Distribution

The range of the river otter includes most of the U.S. and Canada, and it was once common in most of North America. It was once common and widely distributed throughout Illinois as well, but was scarce in most parts of the state by the late 1800s. In Illinois, the river otter has a sporadic distribution, with recent records from 32 counties, but a well-established population in only the northwest corner of the state. There are also smaller populations in southern Illinois, particularly along the Cache River system. Many of the other records probably represent dispersing or wandering individuals, rather than permanent populations of otters.

### Habitat

Though they can spend much of their time on land, river otters are always found near water. As their name implies, they are generally found near rivers and streams, but they also live in sloughs, marshes, and lakes. They tend to be found in higher densities in waters that also have adjacent wetlands and backwaters. Otters require year-round open water and densely wooded cover nearby, particularly those which provide suitable den sites in stream banks or under the roots of trees. Because of their denning habits, otters are often found in areas which also have a high beaver population. Otters are very sensitive to pollution and are not found in areas of poor water quality, though they may use waters which are turbid rather than clear if the water quality is otherwise good. River otters require large amounts of suitable habitat, requiring 3 square miles or as much as 50-100 river miles of habitat.

### Life History

River otters have only a single litter of young per year, beginning at 2 years of age. Otters can have up to 6 young (called pups) at a time, but litters usually consist of only 2 - 4 pups, born in the early spring. Otter pups stay with their mothers during their first year, and have to be taught to swim. River otters use dens for resting, sleeping, and rearing their young. They do not dig their own dens, but use old beaver dens, tree root cavities, overhanging ledges, or logjams.

Like most carnivores, the river otter is an opportunist when it comes to food. They eat primarily fish, but will also eat crayfish, large insects and frogs. They tend to consume whatever will give them the most energy for the least effort, so more abundant, slow-moving, mid-sized prey items will be taken more often than fast, uncommon, or tiny prey.

Though otters are sociable and can be found in family groups, they are territorial, particularly during the breeding season. Otters, like other members of the weasel family, have musk glands near the base of their tails, and will mark their territory using this scent. Otters will frequently travel great distances, and though they are awkward on land, they readily go overland to get from one river to another. Because of this, a number of river otters are accidentally killed while crossing roads. Otters are known as active, playful, inquisitive animals. Much of their "play" is really a way of developing good coordination and maintaining social contact in a family group. Due to their secretive nature, river otters are seldom seen by people.

## Current Status

With settlement of this continent, the increasing human population brought about considerable loss and degradation of the otter's habitat due to agricultural activities, stream pollution and channelization, and urbanization. Excessive, unregulated harvest of this valuable furbearer further reduced its populations, and by the 19th century, its range and numbers in North America had shrunk significantly. It ceased to be important in the Illinois fur trade by about 1900, and was considered to be nearly, if not completely, extirpated from the state by 1943. The trapping season for the otter was closed in Illinois in the late 1920s, and has not been opened since. It was listed as a threatened species in Illinois with the adoption of the first state endangered and threatened species lists in 1977, and changed to state endangered status in 1989.

## Management Needs

Despite a continuous closed season since 1929, river otter populations in Illinois have remained low. Improvement of stream conditions and protection of large tracts of riparian habitat will be needed if the river otter population is to recover in Illinois. Though extant otter populations may be gradually increasing, repopulation of much of its former Illinois range will be slow due to the slow rate of reproduction in this animal. Many states have conducted reintroduction programs to bring the otter back to its former range; in 1994, Illinois also began to release river otters into areas where they formerly occurred. In combination with habitat protection and water quality improvement, it is hoped that this effort will enhance the return of the river otter to Illinois waters.

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### YOU CAN HELP PRESERVE ENDANGERED SPECIES AND ALL NONGAME WILDLIFE

The Department of Natural Resource's Division of Natural Heritage works to protect all species of plants and animals that are not taken by hunters, trappers, or anglers. If you would like to help expand these efforts, you are invited to send a tax-deductible donation of any amount to the "Wildlife Preservation Fund." Money from this fund pays for much of the research and management needed for the preservation of these species. Send your donation to Division of Natural Heritage, Illinois Department of Natural Resources, 524 S. Second, Springfield, IL 62701-1787.

Exhibit 6

# River Otter

*Lontra canadensis* (formerly *Lutra canadensis*)

## DESCRIPTION

The river otter is a large, aquatically-adapted member of the weasel family. This shy and secretive animal is a strong and graceful swimmer, with an ability to dive to depths of about 60 ft. Like other members of its family, the river otter has a long body, short legs, and a long neck. The head is broad and flattened and its muscular, tapering tail typically equals about one third of its total body length. The pelage is dark brown above and lighter below. The lips cheeks, chin, and throat also are a lighter brown (Whitaker and Hamilton 1998).

## BODY SIZE

River otters display sexual dimorphism in body size, with adult males reported to be about 17% heavier and significantly longer than adult females. Average measurements of four adult males from Idaho (Whitaker and Hamilton 1998) were: total length 117.7 cm (range = 115.0 – 120.1, SE 1.05); tail 46.3 cm (range = 44.5 – 47.9, SE 0.77); and hind foot 13.3 cm (range = 12.8 – 13.7, SE 0.19). Six adult females from the same study area had the following average measurements: total length 111.1 cm (range = 107 – 113.2, SE 0.91); tail length 43.7 cm (range = 42.4 – 45.2, SE 0.37); and hind foot 12.7 cm (11.9 – 13.4, SE .26)..

The adult males in the Idaho study area had an average body weight of 9.2 kg (range = 8.0 – 11.0, SE = 0.6), while the body weight of adult females averaged 7.9 kg (range = 7.5 – 8.0, SE = 0.2). These measurements fall within the ranges of river otters from the eastern U.S. as reported by Whitaker and Hamilton (1998). Interestingly, the weight of adult females may decrease after they reach four years of age (Stephenson 1977 as cited in Melquist and Hornocker 1983).

## DISTRIBUTION

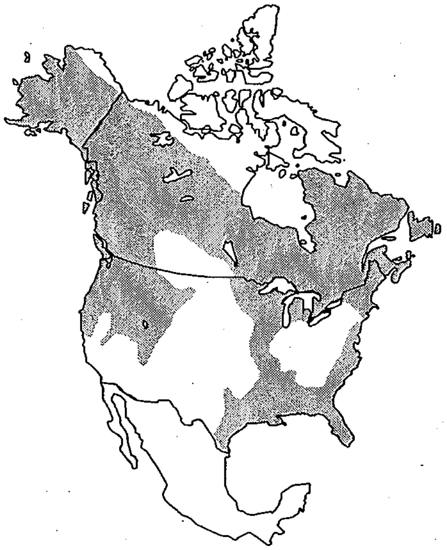


**Figure 1.** Range of the river otter in North America

The current range of the river otter in North America is shown in Figure 1 (from Whitaker and Hamilton 1998). Historically, the river otter occurred throughout much of the U.S. and Canada excluding the drier Southwestern states and the northern tundra of Alaska and Canada (Melquist and Hornocker 1983). Beginning in the 19th century or earlier, river otter numbers and distribution declined significantly (Organ 1989). A 1976 study suggested that river otter were believed to be present in 44 states and 11 Canadian provinces and territories (Deems and Pursley 1978, as cited in Melquist and Hornocker 1983). Whitaker and Hamilton (1998), however, indicate that habitat loss, over-harvesting, and pollution have reduced the otter's range to a third of its original distribution and caused its extirpation from portions of the mid-Atlantic and central U.S. Recent protection and re-introduction efforts in Ohio, Illinois, Indiana, and Pennsylvania have allowed the species to make a comeback in those areas. In 1977, the river otter was included in Appendix II of the *Convention on International Trade in Endangered Species of Wild Fauna and Flora* (CITES), which limited trade of otter pelts. Some states have prohibited harvesting of the river otter to provide additional protection for this species (Melquist and Hornocker 1983).

## MIGRATION

The river otter is non-migratory, but will travel between different foraging locations throughout the course of the year. In Idaho, conservative estimates of average daily distance traveled by otters (including family groups) ranged from 0.4 to 3.1 miles (Melquist and Hornocker 1983). During dispersal and exploration of their home ranges, river otters will travel much greater distances in a single day (i.e., up to 26 miles).

## HABITAT

River otters use both freshwater and brackish habitats. They occur in lacustrine (i.e., lake) and riverine waterbodies,. as well as their associated wetland habitats (Whitaker and Hamilton 1998). Prey availability appears to be the primary factor affecting habitat selection (Melquist and Hornocker 1983). Also of importance is the presence of adequate shelter and limited human activity. Habitat use varies during the course of the year based on accessibility and food availability. For example, mudflats and open marshes in Idaho were often used during the summer, but rarely during the winter when snow and ice limited accessibility. In Florida, river otter will move from temporarily flooded marshes to cypress swamps that include permanent ponds. These swamps represent the little remaining aquatic habitat for both the otter and fish, which are the otter's primary prey, during the driest part of the year (Humphrey and Zinn 1982).

In New England, river otters will preferentially select riverine and lacustrine systems, but will also use estuaries, salt marshes, and most palustrine wetlands. They may also be present in a variety of forest cover types provided a waterbody is nearby (DeGraaf and Yamasaki 2001). In coastal Maine, river otters select habitat associated with beaver flowages, which provided abundant food, stable water levels, escape cover, and resting and dens sites. These areas also are relatively free from human disturbance. Habitat use by river otter in Maine is positively correlated with the length of the stream and the average shoreline diversity (e.g., the amount of shallow habitat available for foraging). River otters in coastal Maine avoid watersheds within mixed hardwood-softwood communities, which are typically less productive, headwater streams (Dubuc *et al.* 1990).

In Massachusetts, river otters use a variety of palustrine, riverine and lacustrine wetland systems with no particular preference for any one community type (Newman and Griffin 1994). In Idaho, river otters use a variety of habitats throughout the course of the year, including mudflats, open marshes, forest streams, swamps and backwater sloughs, large lakes and reservoirs, and smaller ponds. Idaho river otters preferred stream-associated habitats to lakes, reservoirs, and ponds (Melquist and Hornocker 1983).

Within any given habitat, river otters select locations referred to as latrines, where they leave the water to defecate, urinate, scent mark, and groom (Newman and Griffin 1994). Habitat characteristics specifically associated with otter latrines include the presence of rock formations, backwater sloughs, fallen logs, vertical banks, large conifers, points of land, beaver bank dens and lodges, isthmuses, and the mouths of permanent streams (Newman and Griffin 1994, Swimley *et al.* 1998).

River otters also have numerous den and resting sites within their home range that they use over the course of a year. These sites provide river otters with protection as well as isolation (Melquist and Hornocker 1983). Den and resting sites may be located in logjams, riparian vegetation, snow or ice cavities, rip-rap, talus rock, boulders, brush and log piles, undercut banks, boat docks, abandoned dam spillways, and dens constructed by other animals (e.g., beaver, muskrat, woodchuck, fox, or coyote) (Liers 1951, Melquist and Hornocker 1983). Melquist and Hornocker (1983) found that river otters used active and abandoned beaver bank dens and lodges more often than any other den or resting site, probably because they provide shelter as well as underwater egress.

**In the Primary Study Area:** River otter signs were observed at only three locations in the primary study area during the 1998, 1999, and 2000 field surveys. Each of these observations was adjacent to the main stem of the Housatonic River. One in the northern portion of the study area was an apparent latrine site at a section of the river bank with a possible den site offering water access. That site was located at the edge of a floodplain forest. The second observation was in the central portion of the study area, consisting of a scat found at one of the study's scent post stations within a wet meadow at the river edge. The third observation was also a scat, located in an open shrub swamp near the river (refer to Figure 2 below). Table 1 contains a summary of the literature review and observational data on the use by river otters of the natural community types found within the primary study area.

## HIBERNATION

River otters do not hibernate. They remain active throughout the year and actually show an increase in activity level during the winter. Although activity levels generally increase during the winter, travel may be restricted by snow and ice cover. During much of the year river otters are primarily nocturnal, with peak activity occurring around midnight and just before dawn. During the winter, however, river otters appear to be more diurnal (Melquist and Hornocker 1983).

## HOME RANGE AND TERRITORIALITY

Home range for the river otter is often expressed in linear measurements because they typically occur along rivers and lake shores. Melquist and Hornocker (1983) reported home ranges from 5 – 50 linear miles for a population in Idaho. Area home ranges have been estimated from 448 – 14,080 acres (0.7 – 22 sq. mi.) (Melquist and Dronkert 1987, as cited in DeGraaf and Yamasaki 2001). Male river otters typically occupy larger home ranges than females (DeGraaf and Yamasaki

**Table 1.** Habitat use by river otter in the primary study area

| Habitat Codes and Natural Community Classifications | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wetland Habitats | | | | | | | | | | | | | | Terrestrial Habitats | | | | | | | | | |
| ROW | ROW & PAB | SHO | | PFO | | | | PSS | PEM | | WM | VP | SW | MW | HW | | | OF | AGR | RES |
| Medium-gradient stream | Low-gradient stream | Riverine pointbar and beach | Mud flat | Red maple swamp | Black ash-red maple-tamarack calcareous seepage swamp | Transitional floodplain forest | High-terrace floodplain forest | Shrub swamp | Deep emergent marsh | Shallow emergent marsh | Wet meadow | Woodland vernal pool | Spruce-fir-northern hardwood forest | Northern hardwoods-hemlock-white pine forest | Successional northern hardwood forest | Red oak-sugar maple transitional forest | Rich mesic forest | Cultural grassland | Agricultural cropland | Residential development |
| ▨ Y | ▨ Y | Y | Y | | Y | ▨ | | ▨ Y | Y | Y | ▨ Y | | | | | | | | | |

ROW = Riverine Open Water
SHO = Shorelines
PFO = Palustrine Forested
PSS = Palustrine Scrub-Shrub
PEM = Palustrine Emergent
WM = Wet Meadow
PAB = Palustrine Aquatic Bed

VP = Vernal Pool
SW = Softwood Forests
MW = Mixed Forests
HW = Hardwood Forests
OF = Open Fields
AGR = Agricultural Croplands
RES = Residential

Season of Use
B = Breeding
M = Migration
W = Wintering
Y = Year-round
Shading = observed in study area

2001). River otter display a high degree of individual and seasonal variation in home range size. Home range size in Idaho was somewhat influenced by the age, sex, and social status (i.e., solitary versus family group), although no clear association was evident. Adult females with pups are generally restricted to the area around the natal dens in the spring while pups are young.

Home ranges include activity centers, where a river otter spends at least 10% of its time during a given season. Activity centers are located in areas with both an abundant prey base and sufficient shelter (Melquist and Hornocker 1983). Activity centers vary during the course of the year with changing prey availability, which may affect seasonal home range size. For example, Melquist and Hornocker (1983) found that individual home range lengths typically increased during the winter in their Idaho study area.

Other than family groups, otters are generally solitary. They will, however, form temporary associations that may consist of related or unrelated individuals. Home ranges in this species have been shown to overlap extensively, with some otters sharing essentially the same home range. Separation appears to occur at the activity centers, with individuals or family groups using different activity centers within the home range or using the same activity centers, but at different times throughout the day (Melquist and Hornocker 1983). When a food source is abundant and concentrated, such as during a spawning run of fish, river otters may use the same activity center at the same time. River otters do not appear to defend a defined area within their home range that would represent a territory, but rather will defend an area surrounding their immediate physical location (Melquist and Hornocker 1983). Animals using overlapping home ranges or activity centers prevent confrontation through mutual avoidance.

## BREEDING

River otters are polygamous; males mate with more than one female during a breeding season. River otters mate shortly after the young are born. Breeding in the northern part of the range occurs between March and April with estrus beginning soon after parturition and lasting 42 to 46 days (Hamilton and Eadie 1964, Melquist and Hornocker 1983, DeGraaf and Yamasaki 2001). Implantation in this species is delayed for approximately 8 to 9.5 months. Implantation of the embryo occurs approximately in February in New York, earlier in the south (Whitaker and Hamilton 1998). Gestation has been estimated to range from 11 to 12 months, with actual embryonic development lasting 61 to 63 days (Hamilton and Eadie 1964; Melquist and Hornocker 1983). Typically the young are born between February and April, although the timing of birth varies with geographic location (range: November through May). Litter sizes range from 1 – 6 pups, with an average of 2 – 3 pups (mean = 2.6 based on embryo counts) (Hamilton and Eadie 1964, Chilelli *et al.* 1996). Studies in Georgia and Alabama have shown a 50% pregnancy rate in some areas, suggesting that females may breed only every other year there (Whitaker and Hamilton 1998).

## GROWTH AND DEVELOPMENT

Pups weigh about 275 g at birth. They are fully furred, but their eyes are closed and they are toothless. Their eyes open when the pups are about 35 days old and pups are weaned at about five months of age (Liers 1951, Whitaker and Hamilton 1998). They forage with the mother at about 10 to 11 weeks. Pups may remain with their mother until they disperse at 12 to 13 months of age, usually in the fall or winter. Juveniles do not reach adult length until they are three to four years of age even though they may breed at two years (Melquist and Hornocker 1983, Whitaker and Hamilton 1998).

## FOOD HABITS AND DIET

The river otter is a carnivorous and piscivorous feeder that occupies an upper trophic level. Fish typically represent the primary prey item in the diet, with crayfish, amphibians, insects, birds, reptiles, and mammals also consumed (Sheldon and Toll 1964, Knudsen and Hale 1968, Toweill 1974, Melquist and Hornocker 1983). In two studies, fish remains were found in 92 – 100% of the analyzed scat (Sheldon and Toll 1964, Melquist and Hornocker 1983). One study in Massachusetts found that otters also consume blueberries when they are available (Sheldon and Toll 1964).

The diet of the river otter varies during the course of the year with changing prey availability. For example, in areas where spawning runs of fish occur, river otters will shift their hunting efforts to these concentrated prey items when they are available (Melquist and Hornocker 1983). Because prey availability also varies with geographic location, the diet of the river otter does differ throughout its range. Crayfish form an important part of the river otter's diet in much of its range, but because crayfish do not occur in the upper Payette River drainage in Idaho, they were not present in the diet there (Melquist and Hornocker 1983). Analyses of stomach contents indicate that some insects present in stomach were the result of direct consumption by river otter, whereas other insects were most likely the result of secondary ingestion (i.e., insects initially consumed by fish) (Toweill 1974, Melquist and Hornocker 1983).

River otters consume a wide range of fish including: Cyprinidae (minnows, carp, northern squawfish), Centrarchidae (smallmouth bass and sunfish), Percidae (yellow perch, darters), Cyperinodontidae (killifish), Catostomidae (e.g., white sucker, largescale sucker), Ictaluridae (bullheads, catfish), Salmonidae (salmon, trout, whitefish, Arctic grayling), Petromyzontidae (lampreys), Gadidae (burbot), Cottidae (sculpins), Gasterosteidae (sticklebacks), Umbridae (mudminnows), and Esocidae (northern pike and pickerel) (Hamilton 1961, Sheldon and Toll 1964, Knudsen and Hale 1968, Toweill 1974, Gilbert and Nancekivell 1982, Melquist and Hornocker 1983).

Prey selection by river otters seems to be dependent upon the species most vulnerable to predation, a function of the prey species' abundance, size, and swimming ability (Melquist and Hornocker 1983). In general, river otters preferentially prey upon slower-moving and schooling species of fish, which are easier to catch, and focus their effort upon the more prevalent and less agile species (Ryder 1955 as cited in Toweill 1974, Whitaker and Hamilton 1998). Sheldon and Toll (1964) also reported that habitat selection, time of day, fish spawning periods, and environmental conditions such as ice cover and water temperature may affect prey selection by river otter. River otters consume fish ranging in size from 2.0 – 50.0 cm. The length of the three predominant prey species in an Idaho study being greater than 30 cm long (Hamilton 1961, Melquist and Hornocker 1983).

Other components of the river otter's diet include: crustaceans (crayfish, crabs, shrimp, pillbugs), mollusks (clams, periwinkles, freshwater mussels), amphibians (adult and larval frogs, salamanders, newts), reptiles (turtles, snakes), insects (Coleoptera, Plecoptera, Diptera, Neuroptera, Tricoptera, Odonata), mammals (*Sorex fumeus, Microtus pennsylvanicus, Clethrionomys gapperi, Peromyscus maniculatis, Thorionys talpoides, Tamiasciurus hudsonicus, Ondatra zibethicus, Castor canadensis, Synaptomys borealis, Lepus americanus, Odocoileus* sp., *Zapus* sp., *Mustela vison*), and birds (Gaviformes, Anseriformes, Ciconiformes, Gruiformes, Passeriformes, and Charadiformes) (Liers 1951, Hamilton 1961, Gilbert and Nancekivell 1982, Melquist and Hornocker 1983).

## ENERGETICS AND METABOLISM

Sample and Suter (1999) report the estimated food ingestion rate for river otters to be 0.9 kg/d (fresh weight of fish or aquatic prey) and the water ingestion rate to be 0.64 L/d.

## POPULATIONS AND DEMOGRAPHY

**Population Densities:** Population densities have been reported from 1 otter per 2.3 miles of waterway to 1 otter per 6 – 11 miles of waterway (Melquist and Hornocker 1983, Melquist and Dronkert 1987 as cited in DeGraaf and Yamasaki 2001).

**Age at Maturity and Life Span:** Both males and females reach sexual maturity by two years of age although males may not successfully breed until they are much older (Liers 1951, Melquist and Hornocker 1983). Some studies indicate that females actually may breed during their first year based on the presence of corpora lutea within the ovaries. Once reaching sexual maturity, females are capable of producing one litter per year and litter size may increase significantly with the age of the female (Docktor *et al.* 1987). The literature provides little information on the life expectancy of river otter in the wild, although Melquist and Hornocker (1983) did report one female that was 10 years old.

**Mortality:** Trapping has historically been one of the primary causes of mortality for the river otter. Direct trapping of river otters still occurs in some states, and some may be incidentally caught in beaver traps (Melquist and Hornocker 1983, Chilelli *et al.* 1996). In addition, river otters may be killed by hunters and in collisions with vehicles and watercraft (Melquist and Hornocker 1983). Because of their upper position in the food chain and their aquatic habits, river otter are susceptible to environmental contaminants, including dioxin, mercury, and polychlorinated biphenyls (PCBs) that are present in the lakes and rivers (Foley *et al.* 1988, Sloan and Brown 1988, Organ 1989, Sample and Suter 1999). Though relatively little is known about the specific effects of PCB contamination on river otter, PCBs have been found to impair reproduction and cause death in the closely-related mink (Platonow and Karstad 1973).

Organ (1989) compared PCB and mercury residues in river otters from 20 different Massachusetts watersheds. While variability was high in all watersheds, individuals from the Housatonic River watershed had the highest mean PCB residues. He also found a correlation between mercury residues in river otters and those in whole-body fish from the same watershed, and suggested that river otters could be used to assess the general background levels on a watershed basis. Mercury levels in adults were higher than those in juveniles, implying bioaccumulation over the animal's lifetime. Studies in Europe also report high levels of PCBs in river otters and suggest that population declines there are due to PCB accumulations in this species (Leonards *et al.* 1997, Traas *et al.* 2001). One study of Eurasian otters (Kruuk and Conroy 1996), however, found no evidence that PCBs accumulated in otters with age.

**Enemies:** Humans are probably the most important enemy of the river otter, affecting this species through direct (i.e., trapping) and indirect (habitat alteration, pollution) means. There appears to be very little published information on natural enemies of the river otter, although there are reports of predation by coyotes (*Canis latrans*) and domestic dogs (Melquist and Hornocker 1983).

## STATUS

**General:** In New England, the river otter is considered to be uncommon based on sightings and trapping data, but may be more common than this information suggests (DeGraaf and Yamasaki 2001). In some parts of Massachusetts, river otter populations have increased to nuisance levels (Whitaker and Hamilton 1998).

**In The Primary Study Area:** Despite thousands of person-hours of field surveys in the study area in all seasons from 1998 to 2000, river otter signs (i.e., scat and tracks) were seen on only four occasions in three locations within the study area (Figure 2). Interestingly, otter signs and a few individuals were observed in nearby reference areas on many occasions, often with very little effort. Reasons for the river otter's conspicuous absence from the primary study area are unknown.

## REFERENCES

Chilelli, M., B. Griffith, and D.J. Harrison. 1996. Interstate comparisons of river otter harvest data. Wildife Society Bulletin 24(2):238-246.

Deems, E.F.J., and D. Pursley. 1978. North American furbearers: their management, research, and harvest status in 1976. International Association of Fish and Wildlife Agencies, College Park, MD, USA.

DeGraaf, R.M., and M. Yamasaki. 2001. New England Wildlife: Habitat, Natural History, and Distribution. University Press of New England, Hanover, NH.

Docktor, C.M., R.T. Bowyer, and A.G. Clark. 1987. Number of corpora lutea as related to age and distribution of river otter in Maine. Journal of Mammalogy 68(1):182-185.

Dubuc, L.J., W.B. Krohn, and R.B. Owen. 1990. Predicting occurrence of river otters by habitat on Mount Desert Island, Maine. Journal of Wildlife Management 54:594-599.

Foley, R.E., S.J. Jackling, R.J. Sloan, and M.K. Brown. 1988. Organochlorine and mercury residues in wild mink and otter: a comparison with fish. Environmental Toxicology and Chemistry 7:363-374.

Gilbert, F.F., and E.G. Nancekivell. 1982. Food habits of mink (*Mustela vison*) and otter (*Lutra canadensis*) in northeastern Alberta. Canadian Journal of Zoology 60:1282-1288.

Hamilton, W.J.J. 1961. Late fall, winter, and early spring foods of 141 otters from New York. New York Fish and Ga me Journal 8(2):106-109.

Hamilton, W.J.J., and W.R. Eadie. 1964. Reproduction in the otter, *Lutra canadensis*. Journal of Mammalogy 45(2):242-252.

Humphrey, S.R., and T.L. Zinn. 1982. Seasonal habitat use by river otters and everglades mink in Florida. Journal of Wildlife Management 46:375-381.

Knudsen, G.J., and J.B. Hale. 1968. Food habits of otters in the Great Lakes region. Journal of Wildlife Management 32(2):89-93.

Kruuk, H., and J.W.H. Conroy. 1996. Concentrations of some organochlorines in otters (*Lutra lutra* L.) in Scotland: implications for populations. Environmental Pollution 92(2):165-171.

Leonards, P.E.G., Y. Zierikzee, U.A.T. Brinkman, W.P. Cofino, N.M. van Straalen, and B.V. van Hattum. 1997. The selective dietary accumulation of planar polychlorinated biphenyls in the otter (*Lutra lutra*). Environmental Toxicology and Chemistry 16(9):1807-1815.

Liers, E.E. 1951. Notes on the river otter (*Lutra canadensis*). Journal of Mammalogy 32:1-9.

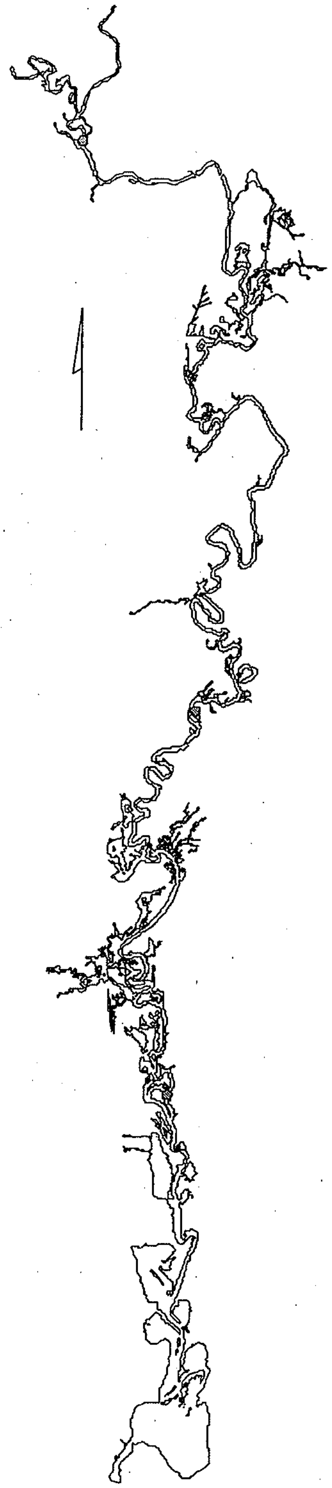


**Figure 2.** River otter sightings in the primary study area

Melquist, W.E., and A.E. Dronkert. 1987. River Otter. p. 626-641. *In* M. Novak, J.A. Baker, M.E. Obbard and B. Malloch (ed.) Wild Furbearer Management and Conservation in North America. Ontario Ministry of Natural Resources and Ontario Trappers Association, Toronto, Canada.

Melquist, W.E., and M.G. Hornocker. 1983. Ecology of river otters in west central Idaho. Wildlife Monograph 83:1-60.

Newman, D.G., and C.R. Griffin. 1994. Wetland use by river otters in central Massachusetts. Journal of Wildlife Management 58(1):18-23.

Organ, J. 1989. Mercury and PCB residues in Massachusetts river otters: comparisons on a watershed basis. Ph.D. Dissertation. University of Massachusetts, Amherst.

Platonow, N.S., and L.H. Karstad. 1973. Dietary effects of polychlorinated biphenyls on mink. Canadian Journal of Comparative Medicine 37:391-400.

Ryder, R.A. 1955. Fish predation by the otter in Michigan. Journal of Wildlife Management 19(4):497-498.

Sample, B.E., and G.W. Suter II. 1998. Ecological risk assessment in a large river-reservoir: 4. Picivorous wildlife. Environmental Toxicology and Chemistry 18(4):610-620.

Sheldon, W.G., and W.G. Toll. 1964. Feeding habits of the river otter in a reservoir in central Massachusetts. Journal of Mammalogy 45:449-454.

Sloan, R.J., and M.K. Brown. 1988. Organochlorine and mercury residues in wild mink and otter: comparison with fish. Environmental Toxicology and Chemistry 7:363-374.

Stephenson, A.B. 1977. Age determination and morphological variation of Ontario otters. Canadian Journal of Zoology 55:1577-1583.

Swimley, T.J., T.L. Serfass, R.P. Brooks, and W.M. Tzilkowski. 1998. Predicting river otter latrine sites in Pennsylvania. Wildife Society Bulletin 26(4):836-845.

Toweill, D.E. 1974. Winter food habits of river otters in western Oregon. Wildife Society Bulletin 26(4):836-845.

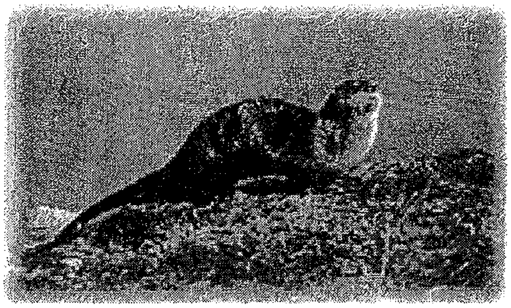
Traas, T.P., R. Luttik, O. Kleeper, J.E.M. Beurskens, M.D. Smit, P.E.G. Leonards, A.G.M. van Hattum, and T. Aldenberg. 2001. Congener-specific model for polychlorinated biphenyl effects on otter (*Lutra lutra*) and associated sediment quality criteria. Environmental Toxicology and Chemistry 20(1):205-212.

Whitaker, J.O., Jr., and W.J. Hamilton Jr. 1998. Mammals of the Eastern United States. 3rd ed. Cornell University Press, Ithica, NY.

# Exhibit 7

# River Otter

**Scientific name** *Lutra canadensis*



### Description

At 35-53 inches from tip to tip, the river otter is Illinois' largest member of the weasel family. A stout tail makes up about 30-40% of its total body length. An otters uses its tail like a rudder while swimming. Adults weigh 10-25 pounds; males are about one third larger than females. Otters have a broad, slightly flattened head, large nosepad, stiff, bristly whiskers, small black eyes, and small rounded ears. Their bodies are muscular and torpedo-shaped, allowing them to move easily through water. The legs are short and have five fully-webbed toes on each foot. The fur is dark brown or reddish brown on the back and light brown, tan, or silver on the throat and belly.

### Distribution & Abundance

River otters were common and found throughout Illinois during early European settlement. Unregulated harvest and habitat loss caused their numbers to decline during the mid-1800s, and sightings were rare by the early 1900s. The trapping season was closed beginning in 1929, but this didn't help much. Pollution was a major problem until the 1970s, when many laws were enacted to improve water quality in our streams and rivers.

River otters were listed as a state threatened species in 1977. Their status was downgraded to state endangered in 1989. It's likely that fewer than 100 otters existed in Illinois at this time. The largest concentration lived along the Mississippi River and its backwaters in northwestern Illinois. A smaller population occurred along the Cache River in the southern tip of the state.

The Department of Natural Resources started working on a recovery plan in the early 1990s. The chances of success seemed pretty high because habitat and water quality were suitable in many parts of the state. Also, the state's beaver population was at near-record numbers (beaver dams create excellent otter habitat) and the state was engaging in some major efforts to conserve wetlands and wooded areas along streams and rivers. From 1994 through 1997, 346 otters were captured in Louisiana using small leghold traps and released in *southeastern and central Illinois.*

Today, otters can be found nearly anywhere in Illinois. Their numbers are still fairly low in many places, but they've increased enough that the state has upgraded their status from state endangered to state threatened. Like all endangered and threatened species, otters are protected by closed hunting and trapping seasons.

### Habitat

Rivers, streams and lakes are key habitats. Those with wooded shorelines and nearby wetlands are best. Water quality isn't a major concern unless it's so bad that fish are scarce. Some types

Newborns are helpless but develop quickly. Their eyes open at about 35 days of age. Brief trips outside the den begin at 10-12 weeks. Females do most of the work when it comes to raising the pups, but males help occasionally once the pups leave the nest. The young otters are coaxed into the water for the first time at about 14 weeks of age. They're weaned by 4 months of age, but often remain with their mother until the following spring. Young females can breed at one year of age, but many wait until they're two.

**Conservation**

Conserving wetlands and wooded areas along streams and rivers are top priorities. Reducing soil erosion and preventing fertilizers and pesticides from washing into streams are important measures, even where otters aren't likely to visit. For example, soil particles washed into a stream can settle when they reach slow-moving water, covering the rock, sand, or gravel that some fish need to lay their eggs and raise young. Fewer fish means less food for otters.

Otters like to use dens and wetlands created by beavers. Protecting the long-term health of the beaver population is an investment in the river otter's future. Trapping is highly regulated in Illinois. Licensed trappers can harvest beavers only at certain times of the year and using only those methods allowed by law. This keeps beavers from becoming scarce while helping to control some of damage they can cause.

Photo & More Information | Tracks & Sign | References | Main Menu | Glossary

Exhibit 8

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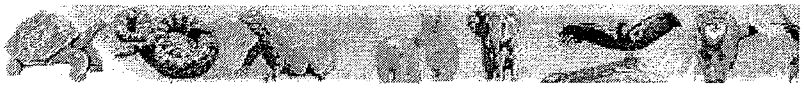

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# OTTER

## Quick Facts

📷 Photo Bytes

**Class:** Mammalia (Mammals)
**Order:** Carnivora
**Family:** Mustelidae
**Genus:** 6 genera
**Species:** 13 species
**Length:** largest—giant otter *Pteronura brasiliensis*, up to 7.8 feet (2.4 meters); smallest—Asian small-clawed otter *Amblonyx cinereus*, up to 3 feet (0.9 meters)
**Weight:** largest—sea otter *Enhydra lutris*, males up to 95 pounds (43 kilograms); smallest—Asian small-clawed otter, up to 11 pounds (5 kilograms)
**Life span:** 15 to 20 years
**Gestation:** from 2 months for smaller species to 5 months for sea otters
**Number of young at birth:** 1 to 5, usually 2
**Size at birth:** 4.5 ounces (128 grams) for smaller species to 5 pounds (2.3 kilograms) for sea otters
**Age of maturity:** 2 to 5 years
**Conservation status:** four species,

**Range:** Africa, Asia, and parts of North, Central, and Sout
**Habitat:** sea otters are found in the Pacific Ocean and alo
coastline, but most otter species live in rivers, lakes, and

## Champion Swimmers

Otters are the only serious swimmers in the weasel family. They spend most of their lives in the water, and they are made for it! Their sleek, streamlined bodies are perfect for diving and swimming. Otters also have long, slightly flattened tails that move sideways to propel them through the water while their back feet act like rudders to steer.

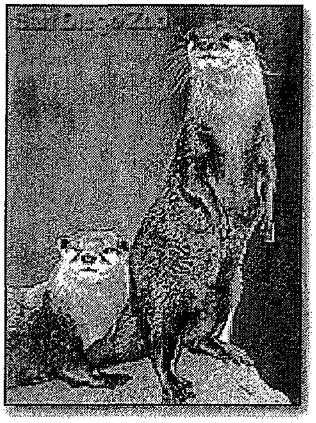
Almost all otters have webbed feet, some more webbed than others, and they can close off their ears and noses as they swim underwater. They can stay submerged for about five minutes, because their heart rate slows and they use less oxygen. They're also good at floating on the water's surface, because air trapped in their fur makes them more buoyant. Have you ever noticed that when an otter comes out of the water, its
sticks together in wet spikes, while the underneath still seems dry? That's bec
have two layers of fur: a dense undercoat that traps air; and a topcoat of long,
guard hairs. Keeping their fur in good condition is important, so otters spend a
grooming. In fact, if their fur becomes matted with something like oil, it can dam
ability to hunt for food and stay warm.

## Party Animals

Otters are very energetic and playful. You might say
to party! They are intelligent and curious, and they ar
busy hunting, investigating, or playing with somethin
to throw and bounce things, wrestle, twirl, and chase
They also play games of "tag" and chase each other,
the water and on the ground. River otters seem to lik
down mud banks or in the snow—they'll do it over and over again! Otters also
of different sounds, from whistles, growls, and screams to barks, chirps, and co
activity is part of the otters' courtship, social bonding, and communication, and
pups need practice, they tend to be even more playful than the adults.

## Life as a Pup

Most otters are born in a den, helpless and with their eyes closed. The mother
of them, often chasing the father away after their birth, although in some specie
may come back after a couple of weeks to help raise them. The babies, called
their eyes and start exploring the den at about one month, start swimming at tw
and stay with their mother and siblings until they are about one year old, when
off on their own.



Male and female Asian small-clawed otters mate for life and share the responsibility of raising pups, although the female is dominant—she calls the shots!

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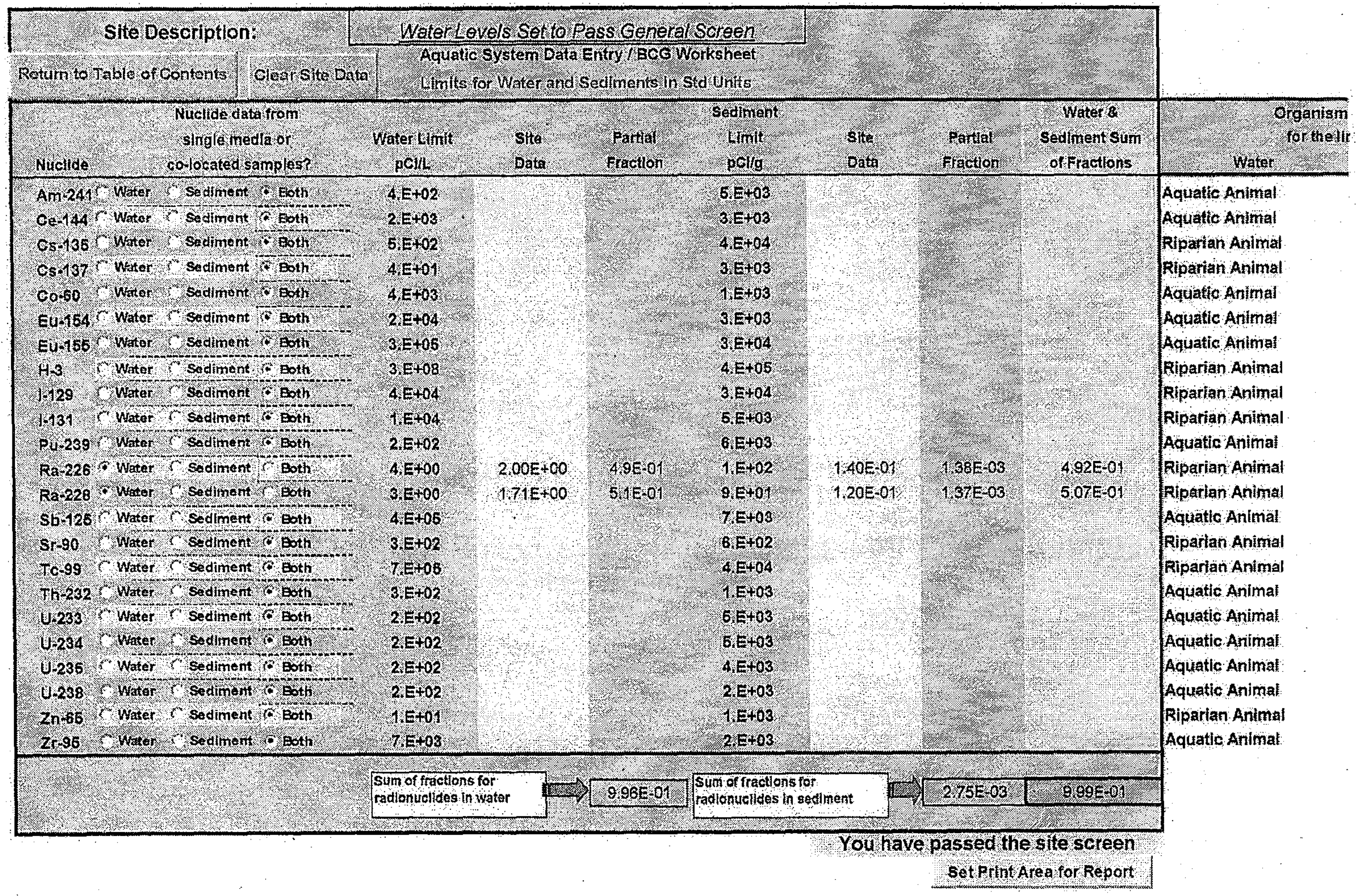
# Exhibit 9



**Site Description:** *Water Levels Set to Pass General Screen*

Aquatic System Data Entry / BCG Worksheet

Limits for Water and Sediments in Std Units

| Nuclide | Nuclide data from single media or co-located samples? | Water Limit pCi/L | Site Data | Partial Fraction | Sediment Limit pCi/g | Site Data | Partial Fraction | Water & Sediment Sum of Fractions | Organism for the lir Water |
|---|---|---|---|---|---|---|---|---|---|
| Am-241 | ○ Water ○ Sediment ● Both | 4.E+02 | | | 5.E+03 | | | | Aquatic Animal |
| Ce-144 | ○ Water ○ Sediment ● Both | 2.E+03 | | | 3.E+03 | | | | Aquatic Animal |
| Cs-135 | ○ Water ○ Sediment ● Both | 5.E+02 | | | 4.E+04 | | | | Riparian Animal |
| Cs-137 | ○ Water ○ Sediment ● Both | 4.E+01 | | | 3.E+03 | | | | Riparian Animal |
| Co-60 | ○ Water ○ Sediment ● Both | 4.E+03 | | | 1.E+03 | | | | Aquatic Animal |
| Eu-154 | ○ Water ○ Sediment ● Both | 2.E+04 | | | 3.E+03 | | | | Aquatic Animal |
| Eu-155 | ○ Water ○ Sediment ● Both | 3.E+05 | | | 3.E+04 | | | | Aquatic Animal |
| H-3 | ○ Water ○ Sediment ● Both | 3.E+08 | | | 4.E+05 | | | | Riparian Animal |
| I-129 | ○ Water ○ Sediment ● Both | 4.E+04 | | | 3.E+04 | | | | Riparian Animal |
| I-131 | ○ Water ○ Sediment ● Both | 1.E+04 | | | 5.E+03 | | | | Riparian Animal |
| Pu-239 | ○ Water ○ Sediment ● Both | 2.E+02 | | | 6.E+03 | | | | Aquatic Animal |
| Ra-226 | ● Water ○ Sediment ○ Both | 4.E+00 | 2.00E+00 | 4.9E-01 | 1.E+02 | 1.40E-01 | 1.38E-03 | 4.92E-01 | Riparian Animal |
| Ra-228 | ● Water ○ Sediment ○ Both | 3.E+00 | 1.71E+00 | 5.1E-01 | 9.E+01 | 1.20E-01 | 1.37E-03 | 5.07E-01 | Riparian Animal |
| Sb-125 | ○ Water ○ Sediment ● Both | 4.E+05 | | | 7.E+03 | | | | Aquatic Animal |
| Sr-90 | ○ Water ○ Sediment ● Both | 3.E+02 | | | 6.E+02 | | | | Riparian Animal |
| Tc-99 | ○ Water ○ Sediment ● Both | 7.E+06 | | | 4.E+04 | | | | Riparian Animal |
| Th-232 | ○ Water ○ Sediment ● Both | 3.E+02 | | | 1.E+03 | | | | Aquatic Animal |
| U-233 | ○ Water ○ Sediment ● Both | 2.E+02 | | | 5.E+03 | | | | Aquatic Animal |
| U-234 | ○ Water ○ Sediment ● Both | 2.E+02 | | | 5.E+03 | | | | Aquatic Animal |
| U-235 | ○ Water ○ Sediment ● Both | 2.E+02 | | | 4.E+03 | | | | Aquatic Animal |
| U-238 | ○ Water ○ Sediment ● Both | 2.E+02 | | | 2.E+03 | | | | Aquatic Animal |
| Zn-65 | ○ Water ○ Sediment ● Both | 1.E+01 | | | 1.E+03 | | | | Riparian Animal |
| Zr-95 | ○ Water ○ Sediment ● Both | 7.E+03 | | | 2.E+03 | | | | Aquatic Animal |

Sum of fractions for radionuclides in water → 9.96E-01

Sum of fractions for radionuclides in sediment → 2.75E-03 | 9.99E-01

**You have passed the site screen**

| responsible<br>miting Dose<br>Source of Calculation | Sediment | Source of Calculation |
|---|---|---|
| *AA Default BIV* | Riparian Animal | *RA-Lumped, Default* |
| *AA Default BIV* | Riparian Animal | *RA-Lumped, Default* |
| *RA-Lumped, Default* | Riparian Animal | *RA-Lumped, Default* |
| *RA-Lumped, Default* | Riparian Animal | *RA-Lumped, Default* |
| *AA Default BIV* | Riparian Animal | *RA-Lumped, Default* |
| *AA Default BIV* | Riparian Animal | *RA-Lumped, Default* |
| *AA Default BIV* | Riparian Animal | *RA-Lumped, Default* |
| *RA-Lumped, Default* | Riparian Animal | *RA-Lumped, Default* |
| *RA-Lumped, Default* | Riparian Animal | *RA-Lumped, Default* |
| *RA-Lumped, Default* | Riparian Animal | *RA-Lumped, Default* |
| *AA Default BIV* | Riparian Animal | *RA-Lumped, Default* |
| *RA-Lumped, Default* | Riparian Animal | *RA-Lumped, Default* |
| *RA-Lumped, Default* | Riparian Animal | *RA-Lumped, Default* |
| *AA Default BIV* | Riparian Animal | *RA-Lumped, Default* |
| *RA-Lumped, Default* | Riparian Animal | *RA-Lumped, Default* |
| *RA-Lumped, Default* | Riparian Animal | *RA-Lumped, Default* |
| *AA Default BIV* | Riparian Animal | *RA-Lumped, Default* |
| *AA Default BIV* | Riparian Animal | *RA-Lumped, Default* |
| *AA Default BIV* | Riparian Animal | *RA-Lumped, Default* |
| *AA Default BIV* | Riparian Animal | *RA-Lumped, Default* |
| *AA Default BIV* | Riparian Animal | *RA-Lumped, Default* |
| *RA-Lumped, Default* | Riparian Animal | *RA-Lumped, Default* |
| *AA Default BIV* | Riparian Animal | *RA-Lumped, Default* |

If you do not pass this screening evaluation, you may examine which organisms are limiting for these pathways, and the parameter values used in their derivation. If you have site specific data, you may adjust input parameters following the instructions in the DOE Technical

***Water Levels Set to Pass General Screening***
***Aquatic System Data Entry / BCG Worksheet***

| Nuclide | Water, pCi/L<br>Partial Fraction | Source of Calculation | Sediment, pCi/g<br>Partial Fraction | Source of Calculation |
|---|---|---|---|---|
| Am-241 | | | | |
| Ce-144 | | | | |
| Cs-135 | | | | |
| Cs-137 | | | | |
| Co-60 | | | | |
| Eu-154 | | | | |
| Eu-155 | | | | |
| H-3 | | | | |
| I-129 | | | | |
| I-131 | | | | |
| Pu-239 | | | | |
| Ra-226 | 4.9E-01 | RA-Lumped, Default | 1.38E-03 | RA-Lumped, Default |
| Ra-228 | 5.1E-01 | RA-Lumped, Default | 1.37E-03 | RA-Lumped, Default |
| Sb-125 | | | | |
| Sr-90 | | | | |
| Tc-99 | | | | |
| Th-232 | | | | |
| U-233 | | | | |
| U-234 | | | | |
| U-235 | | | | |
| U-238 | | | | |
| Zn-65 | | | | |
| Zr-95 | | | | |
| Partial fractions | 1.0E+00 | | 2.75E-03 | |
| Total sum of fractions (water and sediment): | | | | 9.99E-01 |
| Result: | You have passed the site screen | | | |

# CERTIFICATE OF SERVICE

I, Albert F. Ettinger, certify that on December 8, 2004, I filed the attached POST-HEARING COMMENTS OF THE SIERRA CLUB AND ENVIRONMENTAL LAW AND POLICY CENTER. An original and 9 copies was filed, on recycled paper, with the Illinois Pollution Control Board, James R. Thompson Center, 100 West Randolph, Suite 11-500, Chicago, IL 60601, and copies were served via United States Mail to those individuals on the included service list.

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