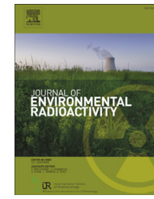
Journal of Environmental Radioactivity 131 (2014) 62–71

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

journal homepage: www.elsevier.com/locate/jenvrad



Influence of Lake Trophic Structure on Iodine-131 Accumulation and Subsequent Cumulative Radiation Dose to Trout Thyroids

Nicole E. Martinez [a,*], Thomas E. Johnson [a,1], John E. Pinder III [b,2]

[a] Department of Environmental and Radiological Health Science, Colorado State University, 1618 Campus Delivery, Fort Collins, CO 80523, United States
[b] Department of Environmental and Radiological Health Science, Colorado State University, 305 W Magnolia # 231, Fort Collins, CO 80521, United States

ARTICLE INFO

Article history:
Received 22 June 2013
Received in revised form
17 October 2013
Accepted 18 October 2013
Available online 7 November 2013

Keywords:
Iodine-131
Fish thyroids
Cumulative dose
Food webs
Modeling
Lakes

ABSTRACT

Iodine-131 is a major component of the atmospheric releases following reactor accidents, and the passage of ^{131}I through food chains from grass to human thyroids has been extensively studied. By comparison, the fate and effects of ^{131}I deposition onto lakes and other aquatic systems have been less studied. In this study we: (1) reanalyze 1960s data from experimental releases of ^{131}I into two small lakes; (2) compare the effects of differences in lake trophic structures on the accumulation of ^{131}I by fish; (3) relate concentrations in fish and fish tissues to that in the water column using empirically estimated uptake (L kg^{-1} d^{-1}) and loss (d^{-1}) parameters; and (4) show that the largest concentrations in the thyroids of trout (*Oncorhynchus mykiss*) may occur from 8 to 32 days after initial release. Iodine-131 concentration in trout thyroids at 30-days post release may be >1000 times that in the water. Estimates of cumulative radiation dose (mGy) to thyroids computed using an anatomically-appropriate model of trout thyroid structure within the Monte Carlo N-particle modeling software predicted cumulative thyroid doses that increased approximately linearly after the first 8 days and resulted in 32-day cumulative thyroid doses that ranged from 6 mGy g^{-1} to 18 mGy g^{-1} per 1 Bq mL^{-1} of initial ^{131}I in the water depending upon fish size. The majority of this dose is due to beta emissions, and the dose varies with positions in the thyroid tissue.

1. Introduction

1.1. Radioiodine in the environment

Reactor accidents and above-ground nuclear detonations release iodine isotopes, notably ^{131}I, into the atmosphere with subsequent deposition onto terrestrial, aquatic and marine ecosystems at both regional and global scales (e.g., Crick and Linsley, 1984; National Cancer Institute, 1999; Gomez-Guzman et al., 2013; Tang and Guo, 2012). The fate of this deposition onto terrestrial systems has received most of the research interest because of the sensitivity and efficiency of the grass–cow–milk–child food chain and the resulting dose to relatively radiosensitive child thyroids (National Cancer Institute, 1999).

Aquatic ecosystems may also be sensitive to ^{131}I depositions because of the typically small iodine concentrations in fresh waters, i.e. ≤7 μg L^{-1} (Poston and Klopfer, 1986; Coughtrey et al., 1983; Tiffany et al., 1969; Vanderploeg et al., 1975) and the metabolic requirements for iodine in many aquatic organisms, especially fish. Concentrations of stable iodine in seawater (~60 μg L^{-1}, Poston and Klopfer, 1986; Coughtrey et al., 1983) are much higher than those in freshwater systems, and the decreasing concentrations of stable iodine in fish tissues from marine to anadromous to freshwater species indicate that iodine levels in fish muscle are influenced by ambient iodine concentrations (Vanderploeg et al., 1975).

Thyroid hyperplasia (a marked increase in thyroid size and/or activity) was seen in spawning Lake Michigan rainbow trout, but was not seen in either spawning anadromous (steelhead) rainbow trout or in spawning Lake Superior trout that had access to food and water supplemented with iodine. The above evidence suggests that the observed thyroid hyperplasia was due to ambient iodine concentrations <1.5 μg L^{-1} (Coughtrey et al., 1983; Robertson and Chaney, 1953).

The current recommended whole-body iodine concentration ratios are considerably larger for freshwater species than marine

* Corresponding author. Tel.: +1 970 491 7575.
E-mail addresses: n.martinez@colostate.edu (N.E. Martinez), Thomas.e.johnson@colostate.edu (T.E. Johnson), jepinder@uga.edu (J.E. Pinder).
[1] Tel.: +1 970 491 0563.
[2] Tel.: +1 970 581 7762.

0265-931X/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jenvrad.2013.10.015

species: ~100–400 L kg^{-1} (depending on trophic level) for freshwater species (Yankovich et al., 2012) and 9 L kg^{-1} for marine species (ICRP, 2009), suggesting that freshwater species are likely to have considerably higher uptake in response to an acute release of iodine.

The rapid assimilation of ^{131}I by fish following an accidental release is demonstrated by Kryshev (1995) for Kiev Reservoir (Fig. 1) where ^{131}I concentrations in the reservoir water 5 days following the Chernobyl accident were >300 Bq L^{-1} and the concentrations in fish muscle were already more than 10 times that in the water. Moreover, the iodine concentration in fish thyroids may be many times that in fish muscle (Vanderploeg et al., 1975), and this suggests the possibility that fish thyroids may be receiving damaging or destructive radiation exposures.

Rapid accumulation of radioactive iodine in fish thyroids with resulting degradation of thyroid-mediated functions has been demonstrated for juvenile rainbow trout (*Oncorhynchus mykiss*, the modern synonym for *Salmo gairdnerii*), who accumulated as much as 17% of intraperitoneal injections of 3.7 MBq ^{131}I in their thyroid regions. Following 6 such monthly injections these fish showed reduced growth rates, reduced skeletal calcification, and absence of sexual development (La Roche et al., 1965, 1966). Fish on iodine supplemented diets that received similar injections accumulated 3–5% of the ^{131}I in the thyroid region and did not display similar reductions in the thyroid mediated functions. Although there is no dosimetry for this study, comparison of thyroid uptake of ^{131}I provides evidence that fish in environments with higher naturally occurring levels of stable iodine are less vulnerable to the deleterious effects of ^{131}I exposure, i.e. marine or even anadromous fish. To what extent similar damage occurs as a result of ^{131}I deposition on to natural systems depends on the cumulative thyroid dose per Bq of deposited ^{131}I.

Although the fate of ^{131}I deposition onto aquatic systems and their watersheds has received considerable study (Bird et al., 1995a,b; Bird and Schwartz, 1996; Gilfedder et al., 2009, 2010), the resulting doses to aquatic organisms have received far less attention. This may be due to the rapid decay of ^{131}I (half-life = 8.041 days) and the perceived limited time for meaningful doses to accumulate.

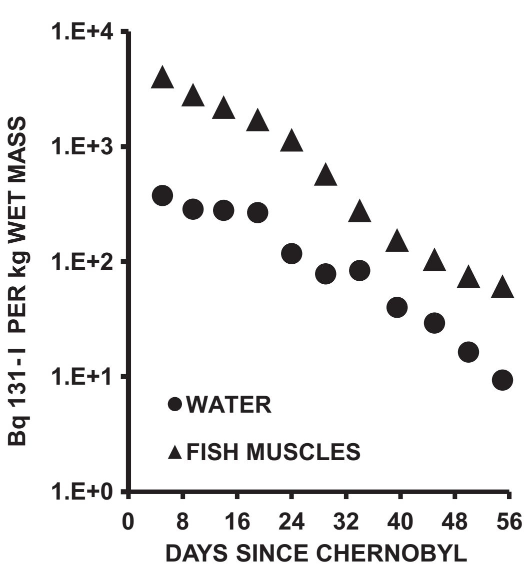


Fig. 1. ^{131}I in Kiev Reservoir. The wet mass concentrations of ^{131}I in water and fish muscles in the Kiev Reservoir in the days following the Chernobyl accident. After day 25, both water and muscle concentrations are declining at rates similar to that for the radioactive decay of ^{131}I.

1.2. Study objectives

In this study we (1) review and reanalyze data on iodine isotopes introduced by accidental releases or purposeful experimental studies into aquatic systems to determine the likely cumulative dose to the thyroid of rainbow trout and (2) relate these doses to properties of the aquatic systems such as food chain complexity. The study comprises four integrated components: (1) empirical models are developed for these systems to describe the temporal patterns of ^{131}I concentrations in water, plants, invertebrates, fish, and specific fish tissues, especially trout thyroids; (2) the radiation dose rate to thyroids as a function of ^{131}I concentrations (i.e., dose conversion factor; mGy d^{-1} per Bq g^{-1}) is estimated using Monte Carlo simulation in an anatomically appropriate model of rainbow trout thyroid tissue; (3) the dose rate per Bq g^{-1} from the Monte Carlo simulation is applied to the temporal patterns of ^{131}I concentrations in trout thyroids to estimate cumulative thyroid dose per initial ^{131}I Bq mL^{-1} in the water; and (4) cumulative doses from hypothetical and historical cases of ^{131}I contamination were evaluated for their potential to affect trout development and survival.

The current methodology employed by the ICRP and within the ERICA Integrated Approach for approximating radiation dose rates to biota calculates whole body dose conversion factors (DCFs) assuming homogenous distribution of radionuclide within an ellipsoidal phantom, with organs modeled as spheres within the ellipsoid, if included (ICRP, 2008; Gómez-Ros et al., 2008). Organ specific DCFs may be conservatively approximated using mass ratios, although this may considerably overestimate the organ dose (Gómez-Ros et al., 2008). A similar approach is taken in this study; however, we have the benefit of specific anatomical dimensions and activity concentration data and can calculate organ specific DCFs directly.

1.3. Thyroid tissue in fish

Fish thyroid tissue shows various arrangements of location, structure and activity levels. Thyroid tissues may be located in or near the mandible as in other vertebrates (Raine et al., 2005; Singh, 1968; Tarrant, 1971), near the eyes, or in the kidneys. Thyroid tissue may be nearly absent with its functions assumed by kidney tissues (Geven et al., 2007). It may be simultaneously located in both the mandible and the kidneys with varying levels of thyroid activity between these locations (Chavin and Bouman, 1965). Even when located near the mandible as in other vertebrates, it may occur as separate individual nodules (or tubules) or as clusters of nodules (Raine et al., 2005; Raine and Leatherland, 2000; Singh, 1968). These variations among and within species have complicated the analysis of ^{131}I accumulation and the estimation of ^{131}I concentrations and concentration ratios for fish.

1.3.1. Sampling fish thyroid tissue

To ensure adequate sampling of thyroid tissue, some studies removed tissue from the mandible area that contained both thyroid and non-thyroid tissues. These samples were described as "thyroid area" samples, and the concentration of ^{131}I in these "thyroid area" samples probably underestimated the ^{131}I concentrations of the true thyroid tissues.

1.3.2. Rainbow trout thyroid activity confined to the mandible area

For rainbow trout immersed in various solutions containing ^{131}I (Hunn and Fromm, 1966), the absorbed ^{131}I was concentrated in the mandible area. There was no indication of ^{131}I deposition in the kidneys or other tissues, and this suggests that the mandible area is the only location with active thyroid tissue for this species.