Introduction

The increasing demand for nuclear energy results in heightened levels of uranium (U) in aquatic ecosystems which present a potential health hazard to resident organisms. We address the effects of U on a well studied model organism: zebrafish, Danio rerio. Our objective was to mechanistically assess how chronic exposure to environmentally relevant concentrations of U perturbs the complex interplay between feeding, growth, maintenance, maturation and reproduction (+ energetics) throughout the life-cycle of an individual.

To this end we analyzed literature-based and original zebrafish toxicity data within a same mass and energy balancing conceptual framework: Dynamic Energy Budget (DEB) theory [5]. The general philosophy is that effects are linked to the amount of internalized compound. Thus in order to understand which physiological process is perturbed by uranium, we must first quantify the uptake-elimination behavior of uranium and second assess how chronic exposure to environmentally relevant concentration of U perturbs the complex energetics of Db models of zebrafish [1].

In this study we included a one compartment toxicokinetic model with time varying coefficients [6] into a fully parameterized zebrafish DEB model [1]. The biomass of an individual is partitioned into two types of material: reserve and structure. Uptake and elimination is through structure and once inside uranium is assumed to be instantaneously partitioned between both reserve and structure. The model was applied to toxicity data in order to detect how the metabolism of zebrafish is affected by uranium.

Results

Uranium targets both somatic maintenance and growth processes

Feeding

No effect internal concentration for growth: 28.9 nM per cm² of structure => 1.5 nM per litre of water

Digestion

No effect internal concentration for maintenance: 32 nM per cm² of structure => 1.5 nM per litre of water

Storage

Growth

Energetics affects toxico-kinetics

20 day exposure to 420 nM from two separate literature studies. The model explains the difference in observed mean bioaccumulation between both studies by dilution by growth (top row) and part of the large inter-individual variability by inter-individual differences in prior feeding history (bottom row).

Observed values of internal concentration for each individual sampled at the last time point (from [3]) as a function of its condition (wet mass over cubed length).

- nmol U/g fresh mass
- mg U/g fresh mass
- Experiment time, d

DEB model predictions for internal concentration after 20 d exposure to 420 nM U assuming inter-individual differences in prior feeding history:

- Simulation of a starved individual
- Simulation of individuals fed 50 to 70 % (left to right) of their maximum feeding capacity

Vol. 100

Dry mass (µg)

Final observed wet mass

Uranium DEB model predictions for wet mass assuming an increase in costs for growth after 20 d exposure to 420 nM U per cm³ of fresh mass.

- Zebrafish DEB model predictions for wet mass assuming no effect of uranium.
- Zebrafish DEB model predictions for wet mass assuming that uranium increases somatic maintenance costs

Conclusions

The Zebrafish DEB model [1] enables us to do the book keeping on mass/ energy flows in and out of each compartment. The dynamics of each of the compartments is very much dependent on the nutritional status of the individual = FEEDING. The model predicted the changes in maintenance costs and growth/feeding capacity based on the internal uranium concentration and availability of energy.

Bioaccumulation data shows a very high inter-individual variability. Part of this variability is explained by the DEB model as resulting from dilution by growth and prior feeding history. Thus energetics affects toxico-kinetics and so effects of uranium. Alternatively effects of uranium affects toxico-kinetics. The significance of this work is that we address how these issues are related and derive conclusions which are independent of experimental protocol and coherent with a very large body of literature on zebrafish eco-physiology.

The amount of initial reserve and amount of reproduction material in combination with feeding for a given female condition the intensity of effects. Thus growth and reproduction for adult data should not be averaged for groups of adults if we want to make sense of toxicity data and derive No Internal Effect concentrations.

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References:

Figure labels:
- Final observed wet mass
- Zebrafish DEB model predictions for wet mass assuming no effect of uranium.
- Zebrafish DEB model predictions for wet mass assuming that uranium increases somatic maintenance costs

Figure captions:
- Figure 1: Bioaccumulation data shows a very high inter-individual variability. Part of this variability is explained by the DEB model as resulting from dilution by growth and prior feeding history.
- Figure 2: Energetics affects toxico-kinetics. The significance of this work is that we address how these issues are related and derive conclusions which are independent of experimental protocol and coherent with a very large body of literature on zebrafish eco-physiology.