Journal of Environmental Radioactivity 171 (2017) 189–199

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

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

Radiocesium in migratory aquatic game birds using contaminated U.S. Department of Energy reactor-cooling reservoirs: A long-term perspective

Robert A. Kennamer [a, *], Ricki E. Oldenkamp [a, b], James C. Leaphart [a, b], Joshua D. King [a, c], A. Lawrence Bryan Jr. [a], James C. Beasley [a, b]

[a] University of Georgia, Savannah River Ecology Laboratory, P.O. Drawer E, Aiken, SC 29802, USA
[b] University of Georgia, D.B. Warnell School of Forestry and Natural Resources, Athens, GA 30602, USA
[c] University of South Carolina Aiken, Department of Biology and Geology, Aiken, SC 29801, USA

ARTICLE INFO

Article history:
Received 17 August 2016
Received in revised form
16 February 2017
Accepted 22 February 2017

Keywords:
^{137}Cs
Ecological half-life
Lentic ecosystems
Nuclear industry
USDOE Savannah River Site
Wintering waterfowl

ABSTRACT

Low-level releases of radiocesium into former nuclear reactor cooling-reservoirs on the U.S. Department of Energy's Savannah River Site (SRS) in South Carolina, USA, dating primarily to the late 1950s and early 1960s, have allowed examination of long-term contaminant attenuation in biota occupying these habitats. Periodic collections of migratory game birds since the 1970s have documented ^{137}Cs (radiocesium) activity concentrations in birds of SRS reservoirs, including mainly Par Pond and Pond B. In this study, during 2014 and 2015 we released wild-caught American coots (*Fulica americana*) and ring-necked ducks (*Aythya collaris*) onto Pond B. We made lethal collections of these same birds with residence times ranging from 32 to 173 days to examine radiocesium uptake and estimate the rate of natural attenuation. The two species achieved asymptotic whole-body activity concentrations of radiocesium at different times, with ring-necked ducks requiring almost three times longer than the 30–35 days needed by coots. We estimated ecological half-life (T_e) for Pond B coots over a 28-yr period as 16.8 yr (95% CI = 12.9–24.2 yr). Pond B coot T_e was nearly four times longer than T_e for coots at nearby Par Pond where radiocesium bioavailability had been constrained for decades by pumping of potassium-enriched river water into that reservoir. T_e could not be estimated from long-term data for radiocesium in Pond B diving ducks, including ring-necked ducks, likely because of high variability in residence times of ducks on Pond B. Our results highlight the importance: (1) for risk managers to understand site-specific biogeochemistry of radiocesium for successful implementation of countermeasures at contaminated sites and (2) of residence time as a critical determinant of observed radiocesium activity concentrations in highly mobile wildlife inhabiting contaminated habitats.

1. Introduction

Environmental releases of radiocesium can create wide-ranging negative consequences for ecosystem and human health, as well as devastating disruptions to food production systems and human presence (e.g., see Beresford et al., 2016). Although radiocesium contamination has been spread across vast regions of the globe due to nuclear weapons testing and catastrophic nuclear industry accidents, localized low-level releases from nuclear facilities also have occurred, often with inputs directly into aquatic ecosystems and resulting in chronic low-dose exposures. Numerous aquatic ecosystems on the U.S. Department of Energy's 78,000-ha Savannah River Site (SRS; White and Gaines, 2000) in west-central South Carolina, USA have been contaminated by low-level releases of ^{137}Cs (radiocesium) and other radionuclides from nuclear material production activities for national defense dating back to the late 1950s (Carlton et al., 1992, 1994). Many of these releases occurred into several large, man-made, reactor cooling reservoirs (Fig. 1). The Par Pond Reservoir System (PPRS; Fig. 1 inset; Dukes, 1984; White and Gaines, 2000), was created to provide secondary cooling water for heat exchangers at two SRS reactors (P and R reactors). The closed-loop system is comprised of two smaller

* Corresponding author.
E-mail address: rkennamer@srel.uga.edu (R.A. Kennamer).

http://dx.doi.org/10.1016/j.jenvrad.2017.02.022
0265-931X/

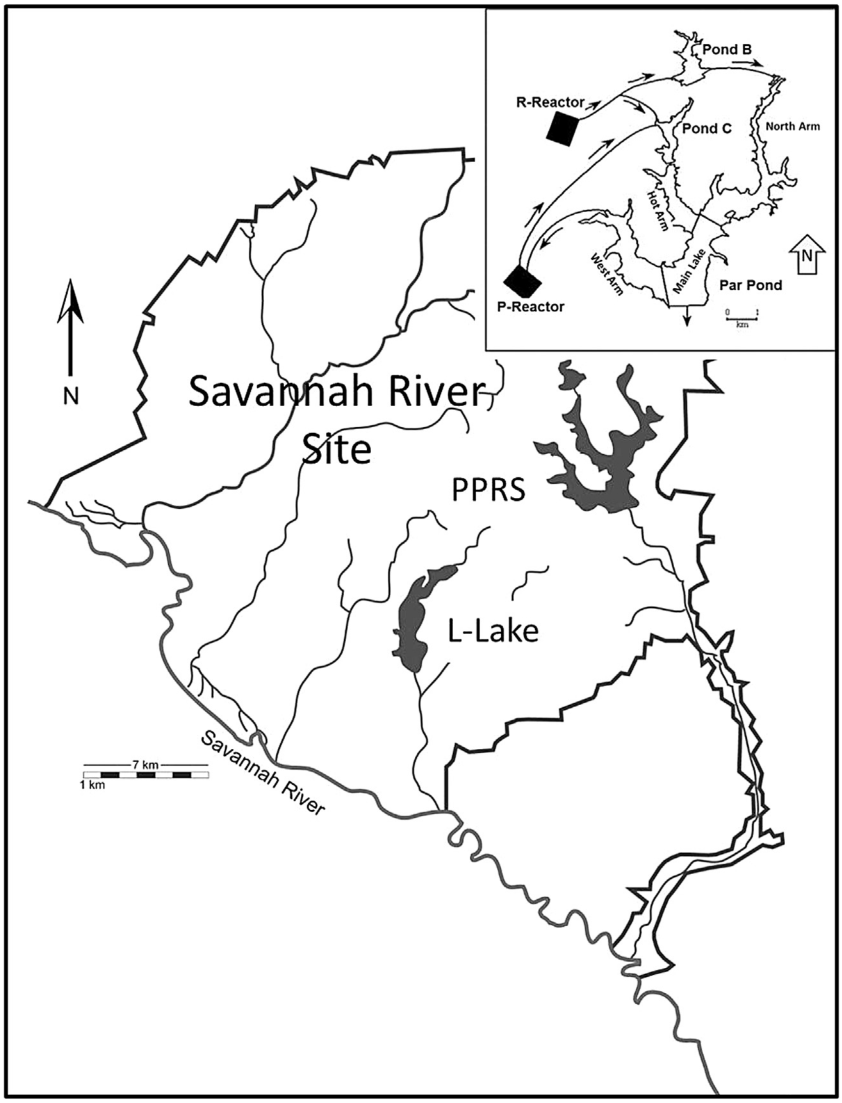

Fig. 1. Diagram of the Savannah River Site (SRS), showing the Par Pond Reservoir System (PPRS) and L-Lake. Inset shows details of the PPRS, including P and R-reactors, Ponds B and C, and Par Pond proper. Included are depictions of canals which carried cooling water periodically contaminated with radionuclides to the various reservoirs during periods of reactor operations.

($\leq$87 ha) impoundments (Ponds B and C), their connecting effluent canals, and the 1130-ha Par Pond reservoir. Radiocesium contaminating events for the PPRS have previously been described by Ashley and Zeigler (1980), Carlton et al. (1994) and Whicker et al. (1990). Briefly, peak introductions of ^{137}Cs to the PPRS occurred during 1963–64, amounting to 4.8 TBq (Carlton et al., 1994). Some portion of that discharge was retained within the Pond B impoundment (Whicker et al., 1990) while much of the balance entered Par Pond North Arm (Fig. 1 inset). The decommissioning of R reactor in 1964 effectively ended effluent circulation through Pond B and Par Pond's North Arm. However, P reactor continued to operate until 1988, when dispersal of its heated effluent through Pond C and the Par Pond Hot Arm ceased (Millings et al., 2003). Historically, biota from the smaller Pond B impoundment has been 17–41 times higher in radiocesium content than that of Par Pond (e.g., Potter, 1987; Potter et al., 1989; Kennamer et al., 1993, 1995). Smaller quantities of other radionuclides including ^{134}Cs (physical half-life [T_p] = 2.06 year) were also discharged into the PPRS during these various release events, but ^{137}Cs would have been the only easily detected gamma-emitting isotope in biota over the last several decades due to the shorter T_p values and limited extent of releases for these additional gamma-emitting radionuclides. Cummins et al. (1991) reported SRS radiocesium releases to the environment (atmospheric and effluent) across a 35-year period with a ^{137}Cs–^{134}Cs ratio of 1000:1 (22 TBq ^{137}Cs, 0.022 TBq ^{134}Cs). Biota from Par Pond in the late 1960s exhibited ^{137}Cs–^{134}Cs ratios of approximately 20:1 (Marter, 1970). We therefore use ^{137}Cs and radiocesium interchangeably. Elsewhere on the SRS, the reactor cooling reservoir L-Lake (Fig. 1) was created in 1985, occupying the floodplain of Steel Creek (White and Gaines, 2000) which had been contaminated decades earlier by effluent releases originating primarily from P reactor (Marter, 1970; Carlton et al., 1992, 1994). Following the construction of L-Lake, the reservoir received little if any input of radiocesium. Because of greater water depths in L-lake relative to other SRS reservoirs and confinement of the contamination in L-Lake primarily to the original streambed, radiocesium activity concentrations measured in L-Lake biota historically have been 2–3 orders of magnitude lower than in biota from the PPRS (R. Kennamer, unpublished data).

Concern arises for environmental releases of radiocesium