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ABSTRACT

The concentration of ^{137}Cs in water and fish from the Winnipeg River, Canada, has been determined upstream and downstream of the Whiteshell Nuclear Research Establishment (WNRE) in central Canada since 1962. Sources of ^{137}Cs to the river system were fallout from nuclear weapons testing, and routine releases from WNRE which have amounted to 1% or less of the regulatory limits for site liquid effluents. From 1962 to 1972, fallout contributed from 67 to 100% of all the ^{137}Cs in the river downstream. Upstream and downstream average annual water concentrations ranged from 0.006 to 0.015 Bq/L, and fresh weight concentrations of ^{137}Cs in the flesh of five fish species averaged from 4 to 20 Bq/kg.

From 1976 to 1982, releases of ^{137}Cs from WNRE contributed from 33% (1982) to 75% (1979) of the total ^{137}Cs downstream. The WNRE contribution was reflected in concentrations in water downstream of 0.010 to 0.025 Bq/L, and average concentrations in fish downstream of 6 to 28 Bq/kg. Over the same period, five species of upstream fish contained average annual concentrations of ^{137}Cs ranging from 1 to 4 Bq/kg. Fish-eating species, including walleye (*Stizostedion vitreum*) and pike (*Esox lucius*), typically averaged two to four times greater ^{137}Cs concentrations than the bottom feeding species, including red sucker (*Moxostoma macrolepidotum*), white sucker (*Catostomus commersoni*), and whitefish (*Coregonus clupeaformis*).

Bioaccumulation factors were calculated for all fish, and, in general, the average values for fish-eating species ranged from 1200 to 2500 (wet weight), and for bottom feeders from 300 to 1000, with some noted exceptions. These bioaccumulation factors are somewhat lower than values reported in the literature for waters with similar chemical characteristics.

The radiological dose implications to man from water and fish consumption were assessed. For consumption rates recommended for dose assessment, the average annual dose equivalent to individuals in the critical group would be less than 0.025 mrem for water consumption, and 0.5 mrem for fish ingestion.

1. INTRODUCTION

The concentration of ^{137}Cs in water and fish from the Winnipeg River, Canada, has been measured upstream and downstream of the Whiteshell Nuclear Research Establishment over a span of 20 a. Data from approximately 1000 fish of five species are summarized in this report, and the measured bioaccumulation factors for radiocesium in fish flesh are compared to values recommended in models for dose calculations in the absence of site-specific data.

The bioaccumulation factor (BF) is the ratio of the radionuclide concentration in an aquatic organism to that in the surrounding water. Such factors are used in environmental transfer models to predict the nuclide concentrations in aquatic biota due to nuclide releases into the water. Human consumption of the aquatic biota results in the transfer of radionuclides to man. Since fish are the primary freshwater organism consumed by man, bioaccumulation factors for fish are necessary to estimate the radionuclide [1,2] transfers for this food pathway. It has been demonstrated that fish consumption is the dominant or critical exposure pathway to man for ^{137}Cs in a freshwater environment.

The accumulation of ^{137}Cs in fish has been observed and studied by many, since it is a significant component of nuclear weapons fallout and is present in effluents discharged from nuclear facilities, and because it has a relatively long half-life (about 30 a). The uptake of ^{137}Cs by fish appears to be regulated by many factors, and has been shown to vary considerably between lakes of different limnological types [3]. The relationship between the potassium concentration in water and the uptake of cesium by fish has been studies [4,5], and the influence of potassium concentration on fish bioaccumulation factors has been quantified within broad ranges [6], showing an inverse relationship. Other factors shown to contribute to the variability in measured bioaccumulation factors for ^{137}Cs are the concentration of stable cesium in the environment [4,7] and the suspended solids content of the water [8]. A comprehensive treatment of the variation of bioaccumulation factors for radiocesium in fish is given by Vanderploeg et al., 1975 [8].

2. STUDY AREA

The Whiteshell Nuclear Research Establishment (WNRE) is located on the east bank of the Winnipeg River in central Canada (Figure 1). This facility, owned and operated by Atomic Energy of Canada Limited, includes a 60 MW(t) organic-cooled research reactor, and associated nuclear research laboratories. Low levels of radioactivity, amounting to less than 1% of the regulatory limit, are released in liquid effluent to the Winnipeg River during normal operation of WNRE.

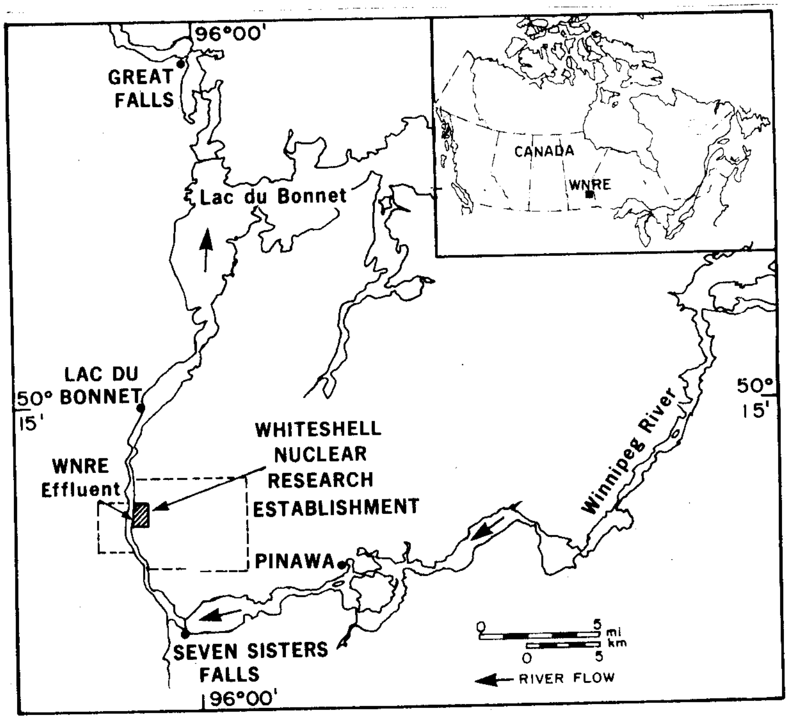

Figure 1: Location of the Whiteshell Nuclear Research Establishment on the Winnipeg River in Central Canada

The Winnipeg River, which receives the liquid effluents from WNRE, is a moderately sized river with an average annual discharge rate of about 1000 m^3/s. The watershed includes about 126 400 km^2 of Precambrian Shield in the temperate zone boreal forest of southeastern Manitoba and western Ontario [9]. The dominant fish species include walleye (Stizostedion vitreum), pike (Esox lucius), red sucker (Moxostoma macrolepidotum), white sucker (Catostomus commersoni), and whitefish (Coregonus clupeaformis). A hydroelectric dam, located approximately 6 km upstream from WNRE, acts as an effective barrier to prevent the mixing of fish downstream of WNRE with the upstream (control) group.

3. METHODS

3.1 Water

Water samples have been collected on a continuing basis at locations upstream and downstream of WNRE since 1962. The upstream location was at Seven Sisters Falls (before 1970) or Pinawa (after 1970), and the downstream locations were at Lac du Bonnet, 8 km downstream, and at Great Falls, 28 km downstream of WNRE (Figure 1). Only Great Falls water data were used in this study, since full dilution of the WNRE effluent occurs between Lac du Bonnet and Great Falls. The Lac du Bonnet data did not provide a reliable estimate of the total Cs flux, and generally underestimated it. Daily samples were combined monthly for analysis. Unfiltered samples, after addition of a stable cesium carrier, were evaporated to dryness, ashed at 425°C for 4 h and then for 2 h at 525°C. The ashed sample was examined by gamma spectrometry and counted for total beta activity (^{40}K equivalent). The ^{137}Cs was then separated radiochemically [10], and the activity measured by beta counting in a gas-flow beta counter.

3.2 Fish

Fish were sampled, using gill nets of graduated mesh sizes from 6.4 to 12.7 cm, at three locations: upstream of Seven Sisters Falls near Pinawa; 0.5 km downstream of the effluent from WNRE, and 5.0 km downstream of the effluent release location (Figure 1). Between 1962 and 1982, sampling was usually conducted in June and/or October. Not all species were obtained every year, and no analyses were available from 1973 to 1975. Fish were measured and weighed, and a flesh sample removed from the bone and the fresh weight determined. This flesh sample was dried overnight at 140°C, digested in concentrated nitric acid, reduced to a tar-like residue by evaporation, and ashed for 16 h at 425°C plus 2 h at 525°C. A stable cesium carrier was added to the ash to determine the efficiency of the cesium extraction. The sample was then analyzed radiochemically, including gamma-ray counting, gravimetric precipitation, and counting in a gas-flow beta counter [10].

4. RESULTS

4.1 Water Analyses

Between 1962 and 1972, the average annual concentrations of ^{137}Cs in river water 28 km downstream of WNRE were similar to the upstream concentrations (Figure 2) of 0.006 to 0.015 Bq/L.

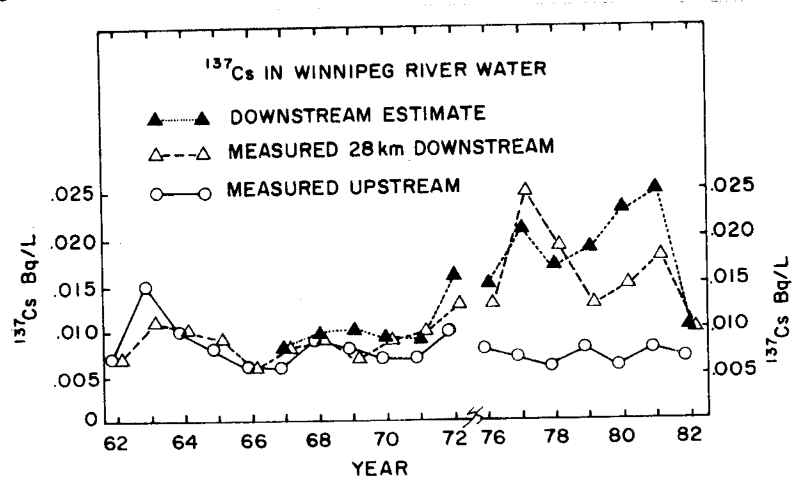

Figure 2: Average annual concentrations of ^{137}Cs in Winnipeg River water measured upstream (Pinawa) and 28 km downstream (Great Falls) of the Whiteshell Nuclear Research Establishment, and the estimated downstream concentrations assuming full dilution of WNRE releases.

The primary source of ^{137}Cs during this period was fallout from nuclear weapons testing.

From 1976 to 1982, the ^{137}Cs concentration upstream from WNRE remained fairly uniform, ranging from 0.006 to 0.008 Bq/L averaged over the year. Within any one year, monthly means ranged from about 0.004 to 0.010 Bq/L. Downstream from WNRE, the ^{137}Cs concentration in the water was (i) estimated for each year based on the releases from WNRE being fully diluted by the river flow, and added to the upstream concentration, and (ii) measured at a point 28 km downstream. The annual average downstream water concentrations ranged from 0.010 to 0.025 Bq/L (see Figure 2). In 1982, following improvements to the WNRE Active Liquid Waste Treatment Centre, ^{137}Cs concentrations downstream were reduced to the levels of the years 1962 to 1972.

4.2 Fish Analyses

Over the period 1962 to 1972, when fallout was the principal source of ^{137}Cs, the concentrations in fish flesh upstream from WNRE were not statistically distinguishable from those in downstream fish (see Figure 3).

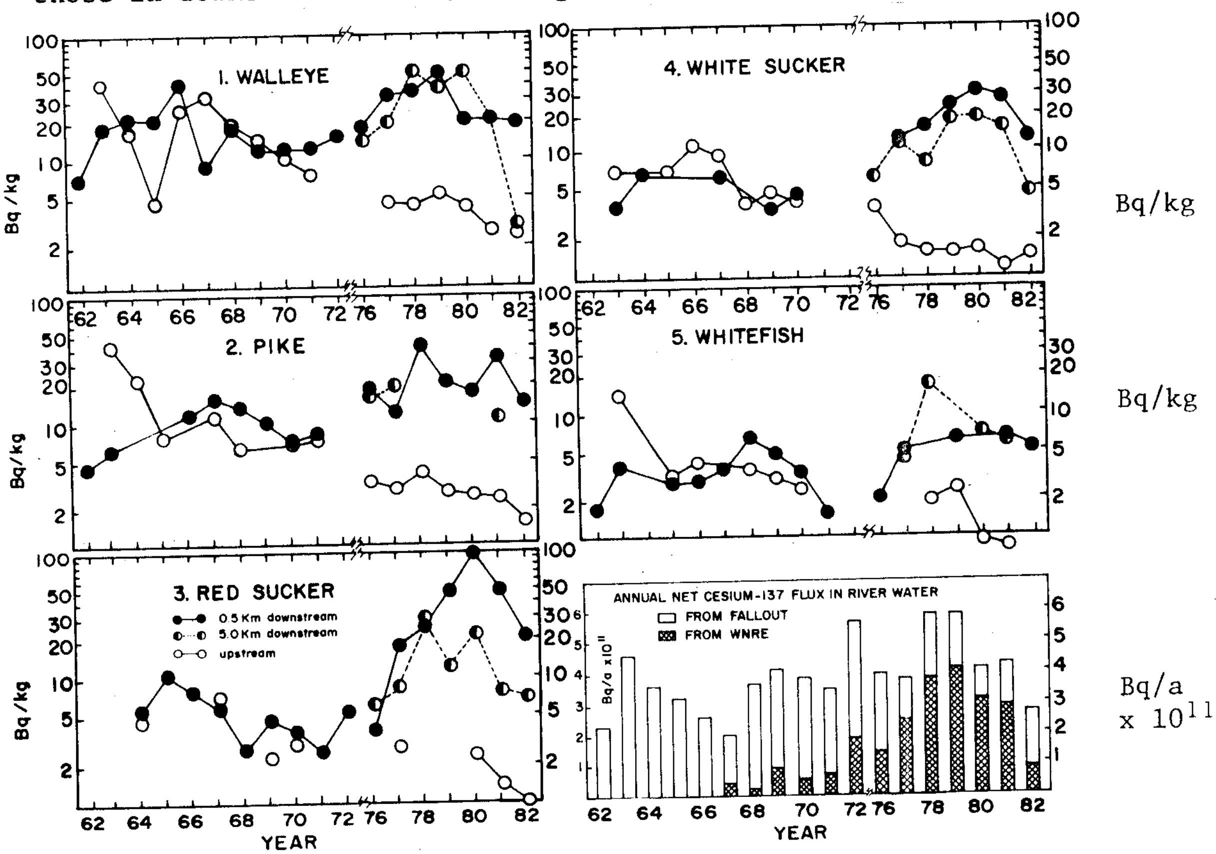

Figure 3: Average annual concentrations of ^{137}Cs in the flesh of five fish species upstream and downstream of WNRE, and contribution from fallout and from WNRE releases to the ^{137}Cs flux in the Winnipeg River.

The average fish flesh concentrations measured for the 1962 to 1966 period were comparable to the average values reported for Red Lake, Minnesota, U.S.A. [11]. Values observed for pike and whitefish during the peak fallout year of 1963 were two to three times lower than those for oligotrophic Finnish Lakes in the same year [3]. Whicker et al. [12] reported an average ^{137}Cs concentration in trout flesh in mountain lakes in Colorado, U.S.A., of about 44 Bq/kg for the period 1965 to 1970, which was about three times greater than those for walleye and pike in the Winnipeg River for the same period. Other North American data were within the ranges observed in Winnipeg River fish from 1969 to 1972, including measurements in small lakes in Michigan [13], Wintergreen Lake [7], and Lake Michigan [14]. The decline in ^{137}Cs concentration in pike flesh in the Winnipeg River since 1967 was proportionately similar to the decline observed in Lake Ulkesjön, Sweden [5], although the Swedish dry weight data were more than an order of magnitude greater than the wet weight concentrations observed in this study.

During the period 1976 to 1982, releases of ^{137}Cs from WNRE exceeded the annual upstream river flux (total ^{137}Cs suspended in the river water discharge volume) in five of the seven years (Figure 3). These releases were reflected in downstream fish flesh concentrations of ^{137}Cs that were greater than upstream concentrations (Figure 3) for all fish species, where within-year statistical comparisons were possible. A comparison of two groups of downstream fish (those taken 0.5 km and 5.0 km downstream of WNRE) showed that only one species, red sucker, exhibited statistically significant differences between 1979 and 1982. The ratio of flesh concentrations 0.5 km downstream to 5 km downstream was about 5:1 in red sucker. Measurements of ^{137}Cs in the sediment at these locations approximated the same ratio, averaging 5.9 Bq/g 0.5 km downstream and 1.1 Bq/g 5 km downstream. Since the red sucker is a bottom feeder and ingests large amounts of sediment with its food, the concentrations in flesh appeared to be directly related to the amounts of radiocesium in the sediments.

In comparison with recently published Canadian data, the concentrations of ^{137}Cs in walleye, pike, and white sucker upstream of WNRE in 1978 were very similar to those in lake trout, pike, and longnose sucker from Christie Bay in Great Slave Lake [15] in the same year. Walleye (1979) and whitefish (1980) upstream of WNRE had concentrations similar to those in sauger (3 Bq/kg) and whitefish (1 Bq/kg), respectively, taken in the north basin of Lake Winnipeg, about 270 km downstream of WNRE, in the same years [15]. In oligotrophic lakes in Canada, where fallout was the only source of ^{137}Cs, whitefish had flesh concentrations of 80 Bq/kg (Louis Lake, North Saskatchewan, 1978) and 46 to 53 Bq/kg (Experimental Lakes, North-Western Ontario, 1980) [15], which were about six to seven times those in whitefish taken downstream of WNRE.

Combined WNRE fish data for the periods 1962 to 1972 and 1976 to 1982 showed a trophic level effect (see Table I). Walleye and pike, the top carnivores, feed primarily on other fish. Red sucker, white sucker, and whitefish are primarily bottom feeders, consuming invertebrate prey that reside on or in the bottom sediments. For the period 1962 to 1972, the combined data show approximate agreement with the three-fold increase in cesium concentration between successive trophic levels, in accord with observations by others [8,16].

Fish Species	1962 - 1972 Bq/kg (wet weight)				1976 - 1982 Bq/kg (wet weight)			
	Upstream		Downstream		Upstream		Downstream	
	n	x SE	n	x SE	n	x SE	n	x SE
Walleye	44	20±2.3	72	17±1.5	41	4.1±0.2	106	28±2.4
Pike	22	11±2.6	31	10±1.2	56	2.9±0.2	57	22±2.3
Red Sucker	11	3.5±0.9	58	5.2±0.5	29	2.0±0.3	118	27±4.4
White Sucker	33	7.0±0.9	29	4.5±0.5	35	1.7±0.2	56	16±1.7
Whitefish	14	4.6±1.1	58	3.8±0.5	10	1.2±0.2	84	6.1±0.4

n = number of fish sampled; x = mean; SE = 1 Standard Error

Table I: Average concentrations of ^{137}Cs in the flesh of five fish species over two time periods (combined data) upstream and downstream of WNRE.

For the upstream data from 1976 to 1982, the trophic level effect is diminished, but still suggested (Table I). Downstream for the 1976 to 1982 period, the ^{137}Cs concentration in red sucker flesh was similar to that in pike and walleye (Table I). As noted previously, the ingestion of large amounts of sediment by the red sucker could increase the uptake of sediment deposited radionuclides relative to other fish species.

4.3 Bioaccumulation Factors

Bioaccumulation factors (BFs) were calculated for the five fish species over all years of available data, and the annual averages are summarized in Table II. These BFs are the ratio of ^{137}Cs concentration in fish flesh (Bq/kg wet weight) to the concentration in water (Bq/L). Traditionally, only a single conservative bioaccumulation factor is used for each nuclide considered in environmental models, and the choice and limitations of such values have been discussed [8,17].

A: ^{137}Cs UPSTREAM BIOACCUMULATION FACTORS

YEAR	^{137}Cs Bq/L Water	Walleye **n	Walleye BF	Pike n	Pike BF	Red Sucker n	Red Sucker BF	White Sucker n	White Sucker BF	Whitefish n	Whitefish BF
1962	*7.1E-3							2	480	2	930
1963	1.5E-2	2	1070	2	2720						
1964	9.7E-3	2	1760	1	2320	1	470				
1965	7.8E-3	2	590	1	1010			6	960	4	400
1966	6.0E-3	6	4330					6	1970	1	670
1967	6.2E-3	6	5420	1	1820	2	1130	4	1580		
1968	9.1E-3	6	2160	3	680			6	430	1	390
1969	7.8E-3	6	1860			6	300	5	630	3	370
1970	7.4E-3	6	1380	12	990	2	390	4	570	3	320
1971	7.3E-3	8	1050	2	1070						
1972	1.1E-2										
1976	7.8E-3			10	440			3	470		
1977	7.4E-3	8	622	14	410	4	380	2	260		
1978	6.0E-3	10	733	7	680			3	270	2	320
1979	5.8E-3	6	897	2	480			2	280	1	410
1980	5.7E-3	7	737	6	460	7	420	11	300	3	160
1981	8.0E-3	4	338	13	310	9	180	8	150	4	100
1982	6.6E-3	6	379	4	240	9	150	6	230		

*7.1E-3 = 7.1 x 10^{-3}; **n = number of fish

B: ^{137}Cs DOWNSTREAM BIOACCUMULATION FACTORS

YEAR	^{137}Cs Bq/L Water	Walleye n	Walleye BF	Pike n	Pike BF	Red Sucker n	Red Sucker BF	White Sucker n	White Sucker BF	Whitefish n	Whitefish BF
1962	7.1E-3	4	1000	2	620					3	240
1963	1.5E-2	3	1210	3	410			6	250	4	250
1964	9.7E-3	2	2230			2	570	2	720		
1965	7.8E-3	5	2720			6	1320			8	350
1966	6.0E-3	12	5250	4	1950	6	1300			9	480
1967	7.8E-3	6	1130	6	2000	12	730	5	820	7	450
1968	9.6E-3	7	1850	1	1420	6	270			15	580
1969	1.0E-2	6	1210	4	1030	4	470	10	350	6	480
1970	8.7E-3	8	1400	6	840	9	440	6	540	2	490
1971	9.1E-3	13	1380	5	910	10	290			4	170
1972	1.6E-2	6	950			3	340				
1976	1.5E-2	25	1140	14	1210	16	330	5	440	2	130
1977	2.1E-2	16	1070	3	710	14	590	10	620	24	230
1978	1.7E-2	12	2620	3	2410	12	1620	6	720	4	960
1979	1.9E-2	14	2350	15	1160	30	1920	7	1110	19	300
1980	2.3E-2	12	1730	6	770	14	2470	11	970	10	300
1981	2.5E-2	13	840	12	1200	18	1060	8	900	19	240
1982	9.8E-3	14	1790	6	1490	14	1930	9	1050	6	530

Table II: Average annual bioaccumulation factors for ^{137}Cs in Winnipeg River fish.

Our data for ^{137}Cs showed a large variation in bioaccumulation factors within any one year, between years, and among fish species. The following Table III summarizes results over two time periods upstream and downstream of WNRE.

Fish Species	1962 - 1972 ^{137}Cs BF		1976 - 1982 ^{137}Cs BF	
	Upstream	Downstream	Upstream	Downstream
Walleye	2500±290	2100±260	640±38	1600±140
Pike	1200±170	1400±190	420±29	1200±120
Red Sucker	480±140	720±74	300±52	1460±225
White Sucker	990±150	560±76	260±24	860±83
Whitefish	470±64	470±54	190±40	310±25

Table III: Average Bioaccumulation Factors (± 1 Standard Error) for ^{137}Cs in the flesh of five fish species.

The averaged BFs in Table III exhibit the expected trophic level effect shown in Table I. In general, the BFs for each species in Table III group reasonably well, with the following two exceptions: 1) the red sucker downstream of WNRE had an unexpectedly higher BF from 1976 to 1982, probably due to sediment ingestion, 2) the upstream BFs from 1976 to 1982 were markedly lower than those for other locations and time periods, for all five fish species. The reasons for this are unknown. The concentration of ^{137}Cs has declined in these fish, in spite of the fact that upstream water concentrations have remained about the same for the past 10 years (see Figures 1 and 2).

Excluding the above exceptions, the BFs for ^{137}Cs in the bottom feeding fish listed in Table III ranged from 300 to 1000, and the BFs for piscivorous fish (walleye and pike) ranged from 1200 to 2500. In comparison with other waters also containing about 1.3 mg/L potassium, these Winnipeg River BFs for ^{137}Cs fall in the lower range of values reported in the literature [8]. The use of Vanderploeg's formula [8] for calculating BFs for fish in turbid water would provide a reasonable approximation of the measured BFs in the Winnipeg River. However, the Winnipeg River, with a suspended solid content of less than 20 mg/L, would not be classified as turbid, and therefore the use of chemical data alone would tend to overestimate the bioaccumulation factor.

5. RADIOLOGICAL DOSE IMPLICATIONS

5.1 Drinking Water

Average annual concentrations of ^{137}Cs in river water downstream of WNRE ranged from 0.010 to 0.025 Bq/L from 1976 to 1982 (Figure 2). The maximum acceptable and target concentrations recommended for Canadian drinking water are 50 Bq/L and 5 Bq/L, respectively [18]. These concentrations are derived on the basis of limiting the radiation dose received from water consumption to 1% and 0.1% respectively, of the ICRP recommended annual occupational dose equivalent limit [19], based on a daily intake of 2 litres (730 L/a). The observed concentrations of ^{137}Cs in downstream water were 200 to 500 times lower than the target concentration, and 2000 to 5000 times lower than the maximum acceptable concentration in the Canadian guidelines. The radiological dose to people drinking this water would be less than 0.025 mrem/a.

5.2 Fish Ingestion

The consumption of fish by humans has been identified as the dominant or critical pathway for ^{137}Cs in a freshwater environment [1,2]. The five fish species identified in this study are all edible species. The average downstream concentration of ^{137}Cs in fish flesh during the 1976 to 1982 period was about 20 Bq/kg (Table I). The quantity of fish that would have to be consumed to correspond to water consumption at the maximum acceptable concentration (Section 5.1) would be about

1800 kg of the downstream fish in one year (about 5 kg per day). For dose-assessment studies, a consumption rate of about 20 kg/a is recommended for individuals in the critical group [20]. The resulting radiological dose would be approximately 0.01% of the occupational limit, that is, approximately 0.5 mrem/a.

The average of the measured BFs for downstream fish from 1976 to 1982 was about 1000 (Table III). The BF used in calculating WNRE release limits for ^{137}Cs to the Winnipeg River is 3000 [21]. The use of this bioaccumulation factor derived from the literature to estimate radiological dose would have, in this instance, overestimated the dose by a factor of about three.

6. DISCUSSION

The bioaccumulation factors for ^{137}Cs in fish flesh measured in this study showed a high degree of variability among individual fish, but on average were a factor of about three below published values based on the potassium content of the water. The use of published BFs to calculate the release limits for ^{137}Cs from nuclear installations will produce acceptable (and conservative) results. However, the use of a BF for ^{137}Cs to estimate the radiological dose to a population, without site-specific data, will have limited predictive value.

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REFERENCES

[1] WRENN,M.E., JINKS,S.M., COHEN,N., HAIRR,L.M., "^{137}Cs and ^{134}Cs distribution in sediment, water, and biota of the lower Hudson River and their dosimetric implications for man", (Proceedings of the 3rd International Congress of the International Radiation Protection Association, Washington D.C. 1973), (SNYDER,W.S., Ed.), USAEC, Oak Ridge, Tennessee (1974) 285.

[2] SMITTON,C., WILLIAMS,W.M., An environmental monitoring program to assess and control the effects of liquid effluent discharges of low radioactivity to an inland lake, Nuclear Energy 19 2 (1980) 111.

[3] KOLEHMAINEN,S.E., HASANEN,E., MIETTINEN,J.K., ^{137}Cs levels in fish of different limnological types of lakes in Finland during 1963, Health Physics 12 (1966) 917.

[4] KOLEHMAINEN,S.E., The Balances of ^{137}Cs, stable cesium and potassium of bluegill and other fish in White Oak Lake, Health Physics 23 3 (1972) 301.

[5] CARLSSON,S., LIDEN,K., ^{137}Cs and potassium in fish and littoral plants from a humus-rich oligotrophic lake 1961-1976, OIKOS 30 1 (1978) 126.
[6] OPHEL,I.L., "Radiation effects in contaminated aquatic ecosystems and their relation to laboratory studies", Methodology for Assessing Impacts of Radioactivity on Aquatic Ecosystems, IAEA Technical Report Series No. 190, Vienna (1979) 211.
[7] EYMAN,L.D., KEVERN,N.R., Cesium-137 and stable cesium in a hypereutrophic lake, Health Physics 28 May (1975) 549.
[8] VANDERPLOEG,H.A., PARZYCK,D.C., WILCOX,W.H., KERCHER,J.R., KAYE,S.V., Bioaccumulation Factors for Radionuclides in Freshwater Biota, Oak Ridge National Laboratory Rep. ORNL-5002 (1975).
[9] NATIONAL RESEARCH COUNCIL OF CANADA, Radioactivity in the Canadian Aquatic Environment, NRCC 19250 (1983) 292.
[10] GUTHRIE,J.E., GRUMMITT,W.E., Manual of Low Activity Environmental Analyses, Atomic Energy of Canada Limited Rep. AECL-1745 (1963).
[11] GUSTAFSON,P.F., "Cesium-137 in freshwater fish during 1954-1965", Symposium on Radioecology (Proceedings of the Second National Symposium, Ann Arbor, Michigan, May, 1967) USAEC CONF-670503 (1969) 249.
[12] WHICKER,F.W., NELSON, W.C., GALLEGOS, A.F., Fallout ^{137}Cs and ^{90}Sr in trout from mountain lakes in Colorado, Health Physics 23 Oct. (1972) 519.
[13] KEVERN,N.R., SPIGARELLI,S.A., "Effects of selected limnological factors on the accumulation of cesium-137 fallout by largemouth bass (Micropterus salmoides)", Radionuclides in Ecosystems (NELSON,D.J., Ed), U.S. Atomic Energy Comm. Rep. USAEC CONF-710501-P1 (1971) 354.
[14] SPIGARELLI,S.A., Cesium-137 activities in fish residing in thermal discharges to Lake Michigan, Health Physics 30 May (1976) 411.
[15] ELLIOTT,S.E.M., BURNS-FLETT,C., HESSLEIN,R.H., BRUNSKILL,G.J., LUTZ,A., Cesium-137, Radium-226, Potassium-40 and Selected Stable Elements in Fish Populations from Great Slave Lake (N.W.T.), Louis Lake (Saskatchewan), Lake Winnipeg (Manitoba), and Experimental Lakes Ares (Northwestern Ontario), Canadian Data Report of Fisheries and Aquatic Sciences 293 (1981) 20.
[16] PENDLETON,R.C., MAYS, C.W., LLOYD,R.D., CHURCH,B.W., A trophic level effect on ^{137}Cs concentration, Health Physics 11 (1965) 1503.
[17] JINKS,S.M., WRENN,M.E., "Radiocesium transport in the Hudson River Estuary", Environmental Toxicity of Aquatic Radionuclides: Models and Mechanisms, (MILLER,M.W., STANNARD,J.N., Eds.), Ann Arbor Science Publishers Inc., (1976) 207.

[18] HEALTH AND WELFARE CANADA, Guidelines for Canadian Drinking Water Quality 1978, Canadian Government Publishing Centre, Hull, Quebec, Canada (1979) 76.

[19] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Recommendations of the International Commission on Radiological Protection, Pergamon Press, Oxford, ICRP Publication 26 (1977).

[20] U.S. NUCLEAR REGULATORY COMMISSION, Regulatory Guide 1.109 - Calculation of Annual Doses to Man From Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I, USNUREG 1.109 Revision 1 Oct. (1977) 80.

[21] WUSCHKE,D.M., DUNFORD,W.E., Derived Release Limits for Radionuclides in Airborne and Liquid Effluents for the Whiteshell Nuclear Research Establishment, Pinawa, Manitoba, Canada, WNRE-406 (1982) 116.