Pickering Scenario Description – Revision 1
EMRAS Tritium/C14 Working Group

2004 June

BACKGROUND

Small amounts of tritium are released continuously from the CANDU reactors that make up Pickering Nuclear Generating Station (PNGS) on the north shore of Lake Ontario. The releases have been going on for many years and concentrations in various parts of the environment are likely to be in equilibrium. A large number of environmental and biological samples were collected in 2002 from four sites in the vicinity of the station. HTO concentrations were measured in air, precipitation, soil, drinking water, plants (including the crops that make up the diet of the local farm animals) and products derived from the animals themselves; OBT concentrations were measured in the plant and animal samples. These data are offered here as a test of models that predict the long-term average tritium concentrations in terrestrial systems due to chronic releases.

SITE DESCRIPTION

PNGS is made up of two units, each consisting of four reactors. Unit A has been shut down for several years but still releases significant amounts of tritium. Unit B was running at full power during the study period. The land surrounding the station is gently rolling and supports a mixture of uses, including industrial, recreational, agricultural and residential.

The samples were taken at two dairy farms (DF8 and DF11), a hobby farm (F27) and a small garden plot (P2) (Figure 1 and Table 1). All of the sampling sites were located to the northeast of PNGS; the two dairy farms lay about 10 km from the station, the hobby farm about 7 km and the garden plot about 1 km. As dairy farms, DF8 and DF11 yielded much the same sort of samples, including corn, pasture grasses, a variety of grains, milk and meat. In contrast, F27 produced mainly fruit, garden vegetables, chickens and eggs. A limited number of plants are grown at P2 for research purposes and raspberry leaves and grass were sampled.

Meteorological data for the Pickering area are given in Table 2. The air temperatures were measured locally in 2002. The solar radiation data represent long-term average conditions at Toronto, about 25 km west of Pickering. The precipitation data are long-term averages for the Pickering area. The fraction of time that rain falls when the wind blows toward F27 is 0.125; the analogous number for DF8, DF11 and P2 is 0.115. These frequencies are based on long-term average data for Toronto and are believed to be overestimates. The average absolute humidity for the 2002 growing season for the area was 0.012 kg m^{-3}.

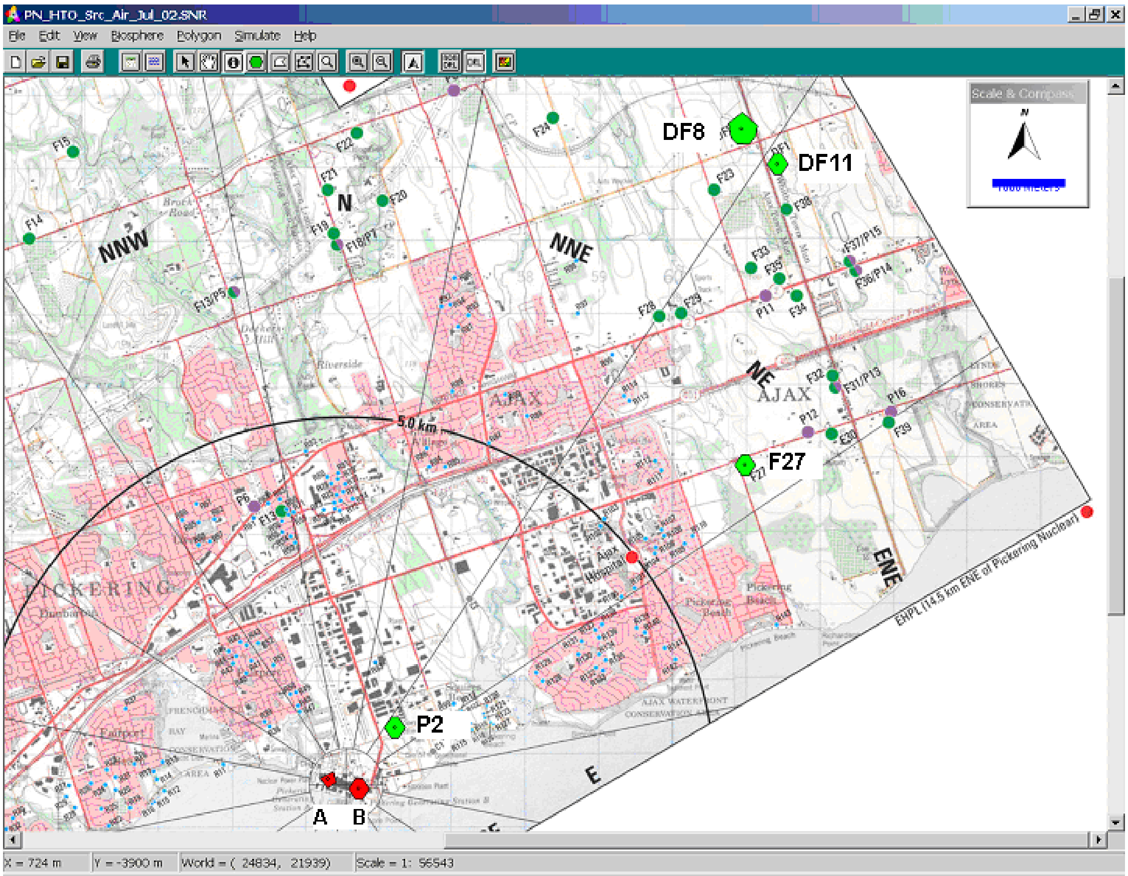

Fig 1. Map of the study area showing the tritium release points (red polygons) and sampling sites (green polygons).

Table 1. Location and description of the sampling sites.

Site	Distance from Unit A	Description
DF8	10,520	Dairy farm, growing pasture grasses, corn and a variety of grains, and raising dairy cows
DF11	10,405	Dairy farm, growing pasture grasses, corn and a variety of grains, and raising dairy cows
F27	7,125	Hobby farm, growing fruit, pasture grasses and garden vegetables, and raising chickens
P2	1,150	Research garden plot growing berries and surrounded by grass

Table 2. Meteorological data for the Pickering area.

Month	Air Temperature (C)		Solar Radiation (W m^{-2})		Rainfall
	Daily mean	Mean daily max	Daily mean	Mean daily max	(mm)
May	9.2	14.5	230	658	72.5
June	16.3	21.9	254	708	64.5
July	20.9	27.6	254	717	68.4
August	20.5	27.3	216	642	77.6
Sept	18.6	25.2	163	528	66.9

FARM PRACTICES

The cows at DF8 and DF11 are fed total mixed ration (TMR), a blend of various feeds harvested in the previous year. The make-up of the TMR at the two farms is shown in Table 3. The corn silage, feed corn, baled hay, haylage and barley are all obtained locally. The silos containing corn silage are filled annually in September. The haylage silos are filled two to three times per year, depending on the growing season. All of the other feed components (brewer's grain, dairy supplement, limestone) are purchased from remote locations and are assumed to contain only background levels of tritium. The total food intake by the cows was estimated by the owners to be 19.0 and 8.8 kg dry weight per day for farms DF8 and DF11, respectively. The latter value is believed to underestimate the true intake.

Table 3. Ratios of feed components in TMR

Type of feed	DF8 (%)	DF11 (%)
Corn silage	45.5	41.9
Feed corn	13.9	22.9
Haylage	12.7	19.6
Brewer's grain	12.7	0
Dairy supplement	7.4	13.8
Baled (dried) hay	4.6	1.9
Barley	3.0	0
Limestone	0.1	0

The chickens raised at F27 were essentially free-range and their food intake was not regulated or monitored. As a result, the make-up of their diet and their intakes could only be estimated (Table 4). The feed corn in their diet was purchased from DF11, and the "other sources" consisted largely of table scraps.

Table 4. Estimated composition of the chicken diet at F27

Type of Feed	% of Diet
Grass	10
Chicken greens (leafy material such as lettuce, beet tops, etc.)	10
Feed corn	30
Oyster shells	3
Apples	5
Carrots	5
Potatoes	5
Green beans	7
Other sources	25

The amount of drinking water ingested by the cows and chickens was not monitored. Irrigation was not carried out to any significant extent at any of the farms during the study period.

TRITIUM MEASUREMENTS

All of the samples were collected in two field campaigns carried out in 2002, the first from July 8 to 10 and the second from September 16 to 18. All of the samples collected in July were oven-dried before the HTO could be extracted and so were suitable for OBT analysis only. The September samples were frozen in their fresh state and were analysed for both HTO and OBT.

Air: Air concentrations at the sites are measured routinely as part of a monitoring program carried out by the utility. Active molecular sieve samplers provided monthly-average concentrations at P2 and annual average concentrations were available from passive diffusion samplers at the other sites. The background air concentration due to tritium sources other than PNGS is 0.19 Bq m^{-3}. Tritium concentrations in the samples were determined using liquid scintillation counting (LSC) techniques.

Precipitation: Precipitation is collected monthly by the utility at DF8, F27 and P2 using gauges with an oil layer to prevent the transfer of tritium between air and water. The water collected was analysed for its tritium content using LSC.

Plants: At the farm sites, samples were collected of each of the plants that made up the animal diets, as well as separate samples of TMR. At F27, additional measurements were made of garden vegetables, root crops and fruit. Table 5 lists the samples collected and their measured water contents. Water equivalent factors (the fraction by weight of water produced when a dry sample is combusted) are also listed. However, these are literature values since the measured values seem low, likely because of the difficulty in collecting all of the water following combustion. Published values of plant yields are also shown in Table 5 for those crops for which data are available. The water in the September samples was extracted by freeze-drying, and HTO concentrations were determined by LSC. The dry matter in the July and September samples was washed with tritium-free water and then oven-dried and combusted in a combustion bomb. LSC of the combustion water yielded non-exchangeable OBT concentrations.

Animal Products: The meat samples from DF8 and DF11 came from calves that were either stillborn or died from complications at birth. The mothers were three years old or younger and were raised exclusively on these farms. A local veterinarian dissected the calves and provided samples of flesh and heart. Additionally, composite milk samples consisting of a mixture of milk from all cows in the herd were collected in July at both farms.

The only animal products sampled at F27 in the July campaign were eggs. Two eggs from mature layers (24-65 weeks old) were combined and a further measurement was made of a composite sample of about 12 eggs. In addition, an immature egg taken from the body cavity of a slaughtered chicken was analysed. In September, in addition to eggs, blood and flesh were also analysed from a single chicken that was probably less than 24 weeks old, as there were no mature yolks in its body cavity. HTO and OBT concentrations in all animal products were determined using the same procedures as for plants.

Table 5. Measured water contents and published yields and water equivalent factors for the sampled crops

Crop type	Site	Month	Plant type	Water content (%)	Water equivalent factor	Yield (kg fw m^{-2})
Forage	DF8	Jul	Hay¤	78.4	0.587	0.47
			Haylage¤	70.5	0.594	0.47§
			Barley	10.5	0.567	0.28
			TMR*	51.9	0.582	
		Sep	Alfalfa	76.4	0.592	0.40
			Baled hay¤	13.8	0.584	0.47§
			Corn silage	61.5	0.579	2.7§
			Haylage	63.7	0.594	0.47§
			Feed corn	25.2	0.572	2.7
			Barley	12.6	0.567	0.28
			Soya meal	11.6	0.600	0.24§
			TMR	54.9	0.582	
	DF11	Jul	Alfalfa	78.0	0.592	0.40
			Baled hay	15.9	0.584	0.47§
			Haylage	34.5	0.594	0.47§
			Feed corn	20.1	0.572	2.7
			TMR*	41.7	0.578	
		Sep	Alfalfa	73.0	0.592	0.40
			Baled hay	11.5	0.584	0.47§
			Corn silage	60.2	0.579	2.7§
			Haylage	36.9	0.594	0.47§
			Feed corn	22.4	0.572	2.7
			TMR*	39.2	0.578	
	F27	Jul	Grass	56.1	0.587	
			Spring wheat	13.3	0.617	0.33
			Soya meal	10.8	0.600	0.24§
		Sep	Grass	76.1	0.587	
			Feed corn	5.0	0.572	2.7
			Spring wheat	10.0	0.617	0.33
			Soya meal	6.0	0.600	0.24§
	P2	Sep	Raspberry leaves	54.8	0.470	
			Grass	75.9	0.587	
Garden vegetables	F27	Jul	Mixed vegetables‡	87.4	0.537	
		Sep	Tomato	81.0	0.543	2.0
			Cucumber	94.0	0.520	1.7
Fruit	F27	Sep	Apple	80.0	0.575	1.9
			Pear	83.2	0.560	0.68
			Raspberry	85.1	0.562	0.16
Root crops	F27	Sep	Carrots and potatoes	81.1	0.543	3.0
			Beet	87.4	0.523	2.3
			Garlic	55.3	0.549	1.7

¤ hay refers to fresh cut pasture; baled hay is dried pasture; haylage is hay that has been stored in a silo
* produced in 2001
‡ beet, cabbage, hot pepper, onion, dill, potato, spinach
§ yield of parent plant in the field

The animal products sampled during the study are listed in Table 6, together with measured water contents and literature values of the water equivalent factors.

Table 6. Measured water contents and published water equivalent factors for the sampled animal products

Site	Month	Animal product	Water content (%)	Water equivalent factor
DF8	Jul	Milk	85.9	0.746
	Sep	Calf flesh	75.7	0.646
		Calf heart	76.6	0.753
DF11	Jul	Milk	87.5	0.746
	Sep	Calf flesh	75.5	0.646
		Calf heart	76.3	0.753
F27	Jul	Egg	74.8	0.803
		Composite egg	71.5	0.803
		Immature egg	47.2	0.803
	Sep	Egg	76.0	0.803
		Chicken blood	80.0	Unknown
		Chicken flesh	74.4	0.697

Drinking Water: Samples of water were taken from the deep wells that supply drinking water for the cows at farms DF8 and DF11 in the September sampling period. Concentrations in drinking water at F27, which comes from a shallow well, are available from routine monitoring by the utility, but not for each month. The value given below in Table 8 is the average for June to December.

Soil: Soil cores were collected at a single location at each site. Three cores 15 cm in diameter and 5 cm deep were taken at each location and composited for analysis. The cores were collected from undisturbed locations in grassed areas or where the soil had lain fallow for some time. No detailed analysis of physical properties was done but the soils at DF8, DF11 and P2 are believed to be loams or clay loams with bulk density, pH and organic content around 1.08 g cm^{-3}, 7.3 and 5.2% dry weight, respectively. At F27, where the cores were taken beside a road, the soil contained more sand. The samples were analysed for their HTO and OBT concentrations using the procedures discussed above for plant and animal samples. Water contents are listed in Table 7.

Table 7. Water content of the sampled soils (% wet weight)

	DF8	DF11	F27	P2
July	-	12.9	25.9	-
September	19.4	14.0	15.0	26.1

Uncertainties: The observed concentrations in all environmental compartments were relatively low, although they were at least a factor 4-5 above background. Counting errors for both HTO and OBT samples were less than 10% in most cases. A further error of perhaps 30% must be added to the air concentrations to account for the uncertainty in the passive diffusion sampler data at DF8, DF11 and F27. An additional uncertainty of about 30% must also be added to the plant and animal concentrations to account for natural variability.

INPUT DATA

Best estimates of the HTO concentrations in air and drinking water at the study sites are shown in Table 8. HTO concentrations in monthly precipitation are given in Table 9.

Table 8. Measured HTO concentrations in air and drinking water. The air concentrations include a background contribution of 0.19 Bq m^{-3}.

Compartment	DF8	DF11	F27	P2
Air concentration (Bq m^{-3})				
2002 May	1.01	1.01	1.56	24
June	1.39	1.39	2.14	33
July	0.93	0.93	1.43	22
August	0.88	0.88	1.36	21
September	0.67	0.67	1.04	16
Air concentration (Bq m^{-3})				
2001 May	0.49	0.49	0.77	12
June	2.83	2.83	4.40	69
July	0.86	0.86	1.34	21
August	1.23	1.23	1.92	30
September	0.66	0.66	1.02	16
Drinking water concentration (Bq L^{-1}) 2002 September	18.6	21.1	24.3*	Not relevant

* average value for June-December 2002

Table 9. Measured monthly HTO concentrations in precipitation.

Month	HTO Concentration in Precipitation (Bq L^{-1})		
	DF8	F27	P2
January	not available	not available	3670
February	not available	18	1350
March	not available	24	347
April	24	29	474
May	69	14	525
June	85	61	579
July	9	14	205
August	49	19	442
September	13	22	452

SCENARIO CALCULATIONS

From the information provided above, calculate

(i) HTO and non-exchangeable OBT concentrations in the plants and animal products listed in Tables 5 and 6. For HTO give the results in Bq L^{-1}; for OBT give the concentration in the combustion water (i.e., Bq L^{-1} water equivalent).

(ii) HTO (Bq L^{-1}) concentrations in the top 5-cm soil layer for each site for each sampling period.

(iii) 95% confidence intervals on all predictions.

The predicted HTO concentrations in plants should reflect average conditions over the growing season and not the measured concentrations at the sampling times. HTO is very mobile in plants and concentrations are strongly dependent on the air concentration in effect in the few hours before sampling. Since these concentrations (or the meteorological and source term data required to calculate them) are not available, no attempt will be made to compare predicted and observed HTO concentrations in plants. Rather, the predictions will be used to help explain differences among model results for OBT concentrations.