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Discussions on Results of Environmental Background Radiation Level Investigation for Tianwan Nuclear Power Plant

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The environmental background radiation level investigation surrounding Tianwan Nuclear Power Plant was conducted for 2 years by China Institute for Radiation Protection. The investigation results are all collected in this paper and discussions are made on some results, such as ^{90}Sr and ^{3}H contents in water bodies, ^{137}Cs and ^{7}Be contents in plant, ^{137}Cs and ^{40}K contents in animal and animal products, ^{137}Cs contents in soil, plant and animal, as well as considerations in choosing indicating organism, etc. Main conclusions are presented as well.

KEYWORDS: nuclear power plant, environment, background radiation investigation

I. Introduction

In compliance with the national relevant laws and standards, the environmental background radiation level investigation must be carried out prior to the construction of a nuclear power plant project. The aims are to obtain the data on radiation levels and on the distribution of natural and artificial radionuclides in the environment, to ascertain their spatial and temporary variations and to provide the background data for the environmental impact assessment of nuclear power plant project under normal operational, accidental and post-accidental conditions.

The environmental background radiation level investigation surrounding Tianwan Nuclear Power Plant (TNPP) was conducted from April 2000 to March 2002 by China Institute for Radiation Protection (CIRP). The investigation involves aerosol, fallout, air, freshwater, soils, terrestrial organisms, seawater, marine sediment, halobios, sea salt and indicating organisms. The analytical items include environmental γ radiation air absorption dose rate, environmental γ radiation accumulated dose, gross-α and gross-β activity, ^{90}Sr, ^{3}H and γ-spectrum analysis. Contents of ^{137}Cs in aerosol, surface water and contents of K in seawater, brine, and sea salt are determined using chemical methods. The γ-spectrum analyses were made of ^{7}Be, ^{134}Cs, ^{137}Cs, ^{58}Co, ^{54}Mn, ^{60}Co and ^{131}I. The contents of ^{238}U, ^{232}Th, ^{226}Ra and ^{40}K in soils and marine sediments are also taken into consideration.

II. Analytical Methods

In compliance with the national relevant standards and the sector standards and according to the literatures and the experiences gained by CIRP, "Monitoring & Analysis Technical Specifications for Environmental Background Radiation Levels Investigation at TNPP", consisting of 27 specifications, has been compiled. The specific measuring method is developed for each of analytical items in the related specification.

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III. Results and Discussion

The averages and ranges of environmental radiation levels and radionuclide contents in media during the 2 years are shown in **Table 1**. Artificial radionuclides ^{134}Cs、^{58}Co、^{54}Mn and ^{60}Co in all kinds of media are not found using γ-spectrometry. The results shown in **Table 1** indicate that there are little variations in the radioactivity levels in most of analytical samples during the 2 years. However, it can be found that the contents of the same one radionuclide in different media of the same type are quite different. Therefore, it is important to compare their contents in different media.

1. ^{90}Sr and ^{3}H in water bodies

(1) ^{90}Sr in water bodies

Table 2 shows the concentrations of ^{90}Sr in different water bodies. The concentration of ^{90}Sr is the highest in groundwater and the lowest in rainwater and seawater. Drinking water samples were mostly taken from treated surface water, but with the only one taken from spring water. So the concentration of ^{90}Sr in drinking water is between in groundwater and surface water, closing to surface water.

(2) ^{3}H in water bodies

The concentrations of ^{3}H in vapor, rainwater, drinking water, groundwater, surface water, seawater and brine were determined in this investigation. **Figure 1** shows the concentrations of ^{3}H in these water bodies and their changes with seasons. There appears a tendency that ^{3}H concentration in rainwater is high in spring and winter and low in summer and autumn, which may be related to the rainfall in different seasons.

The averages of the concentrations of ^{3}H are 1.76±0.61 Bq/L in vapor, 1.08±0.48 Bq/L in rainwater, 1.04±0.05 Bq/L in groundwater, 0.97±0.06 Bq/L in drinking water, 0.88±0.07 Bq/L in surface water, and 0.87±0.14 Bq/L in seawater.

The concentrations of ^{3}H obtained in this investigation are much lower than those obtained in the National Radioactivity Level Investigation organized by the Ministry of Health in 1991[1]. As noted by NCRP Report 62 (1979),

Table 1 Results of environmental background radiation investigation at Tianwan nuclear power plant

	Terrestrial γ radiation (nGy/h)			Aerosol (mBq/m^3)				
	Field γ radiation air absorbed dose rate	Road γ radiation air absorbed dose rate	Field γ radiation accumulated dose	^{7}Be	^{90}Sr	Grossα	Grossβ	^{137}Cs (μ Bq/m^3)
2000.4~2001.3	66±8	79±8	91±8	2.69±1.33	0.048±0.042	0.73±0.38	0.97±0.48	0.61±0.36
2001.4~2002.3	66±7	78±5	89±8	3.24±1.30	0.055±0.045	0.65±0.26	1.21±0.48	0.61±0.44

	Fallout (Bq/m^2 mo.)						Air (mBq/m^3)
	^{232}Th	^{226}Ra	^{40}K	^{7}Be	Grossβ	^{90}Sr	^{3}H
2000.4~2001.3	0.55±0.56	0.44±0.39	13.2±16.8	71.6±63.1	22.8±22.9	0.520±0.495	22.3±12.6
2001.4~2002.3	0.51±0.41	0.39±0.33	9.8±10.6	26.9±18.1	17.4±14.5	0.115±0.208	14.1±7.6

	Rainwater		Groundwater		Surface water		Drinking water (Bq/L)		
	^{90}Sr (mBq/L)	^{3}H (Bq/L)	^{90}Sr (mBq/L)	^{3}H (Bq/L)	^{90}Sr (mBq/L)	^{3}H (Bq/L)	^{90}Sr (mBq/L)	Grossβ	^{3}H
2000.4~2001.3	2.45±3.02	1.15±0.58	7.1±7.1	1.08±0.09	3.1±1.7	0.93±0.09	4.2±1.7	0.10±0.05	0.99±0.10
2001.4~2002.3	0.80±1.25	1.00±0.34	9.3±4.5	0.99±0.10	5.8±3.0	0.84±0.12	7.2±3.1	0.09±0.05	0.95±0.10

Soil (Bq/kg)		^{238}U	^{232}Th	^{226}Ra	^{40}K	^{137}Cs	^{90}Sr
Paddy field	2000	40.7±9.1	62.8±13.0	39.8±6.8	928±113	4.8±2.2	0.8±0.2
	2001	48.2±7.5	63.7±6.4	40.5±2.8	896±100	4.9±2.3	0.9±0.1
Vegetable soil	2000	35.4±11.5	55.0±8.9	35.2±4.3	895±72	3.9±1.6	0.9±0.3
	2001	46.1±6.4	59.5±10.0	39.9±3.9	889±57	4.1±1.6	1.0±0.3
Wheatland	2000	39.7±4.2	56.4±9.7	34.6±4.6	888±84	4.9±1.5	1.1±0.4
	2001	41.4±8.7	53.6±15.9	36.3±5.2	898±112	4.6±1.4	1.2±0.3
Pasture soil	2000	33.5±6.3	55.7±19.5	38.5±8.7	898±76	4.6±2.0	0.9±0.2
	2001	40.6±8.2	53.8±11.4	36.0±5.4	958±105	4.5±2.3	1.0±0.2
Orchard soil	2000	33.1±7.4	41.0±3.2	30.8±3.6	799±284	6.4±0.7	0.8±0.2
	2001	38.9±10.8	44.3±19.2	28.1±10.6	939±175	5.0±0.9	1.1±0.4
Sediment	2000	18.5±2.3	29.3±0.8	17.9±0.4	825±7	2.0±0.2	1.1±0.1
	2001	18.7±0.4	24.0±1.9	16.9±2.2	938±99	1.2±0.1	1.0±0.0

Plant (Bq/kg fresh weight)		^{7}Be	^{137}Cs
Pasture (Dry Sample)	2000	61.1±50.7	0.17±0.11
	2001	51.7±46.8	0.16±0.14
Vegetable	2000	10.7±13.4	0.017±0.009
	2001	6.89±12.1	0.021±0.012
Wheat	2000	0.28±0.24	0.035±0.025
	2001	0.21±0.12	0.033±0.019
Paddy	2000		0.010±0.009
	2001	0.069±0.080	0.009±0.006

Terrestrial indicating organism (Bq/kg)					
Pine needle	2000	^{40}K	^{7}Be	^{137}Cs	^{90}Sr
	2001	94.2±15.8	53.4±49.7	0.10±0.03	4.80±1.16
Tea	2001	85.3±1.6	26.4±0.7	0.10±0.02	0.22±0.17
	2002	767±37	21.4±19.6	0.23±0.02	2.32±0.85

Animal and animal product (Bq/kg fresh weight)		^{40}K	^{137}Cs
Milk	2000	57.9±5.1	0.01±0.01
	2001	52.6±5.2	0.01±0.01
Beef	2000	120±29	0.04±0.02
	2001	76.1±10.1	0.04±0.02
Pork	2000	163±32	0.05±0.07
	2001	93±22	0.04±0.01
Chicken	2000	124±19	0.03±0.01
	2001	97±16	0.04±0.01
Egg	2000	59.2±19.4	0.01±0.01
	2001	42.9±1.5	0.01±0.00
Carp meat	2000	104±28	0.05±0.05
	2001	102±22	0.03±0.03
Carp bone	2000	55.1±19.4	0.07±0.11

	Seawater (mBq/L)				Marine sediment (Bq/kg)					
	^{137}Cs	^{90}Sr	^{3}H (Bq/L)	K (mg/L)	^{238}U	^{232}Th	^{226}Ra	^{40}K	^{137}Cs	^{90}Sr
2000	0.41±0.26	2.08±0.54	0.97±0.15	218±137	37.1±17.8	40.1±14.9	29.4±16.6	820±162	1.33±1.14	0.47±0.24
2001	0.63±0.28	2.00±0.43	0.77±0.07	537±43	30.9±10.7	35.6±12.6	28.0±14.0	738±98	1.54±1.06	0.46±0.35

	Marine fish (Bq/kg fresh weight)				Shrimp & crab (Bq/kg fresh weight)			Seashell & cuttlefish (Bq/kg fresh weight)			
		^{40}K	^{137}Cs	^{90}Sr (10^{-2}Bq/kg)		^{40}K	^{90}Sr(10^{-2}Bq/kg)		^{40}K	^{137}Cs	^{90}Sr(10^{-2}Bq/kg)
2000	Conger pike	58.6±15.7	0.05±0.01	6.8±4.8	Rough shrimp	81±6	110±4	Short-necked clam	61.5±32.5	0.05±0.03	7.3±2.1
2001		81±14	0.06±0.02	2.6±0.8		54.1±2.6	8.1±2.9		56.1±3.0	0.04±0.01	4.9±3.3
2000	Half-smooth tongue-sole	82±32	0.04±0.01	3.6±2.4	Chinese shrimp	85±20	2.8±2.9	Constricted tagelus	35.0±3.2	0.02±0.01	4.3±2.3
2001		102±7	0.04±0.01	3.6±2.3		116±12	6.0±5.9		48.8±36.3	0.03±0.01	8.0±7.3
2000	Blue-spotted mackerel	119±11	0.16±0.15	3.1±2.4	Swimming crab	47.5±27.4	4.0±1.0	Oyster	57.6±17.7	0.03±0.01	7.6±2.6
2001		141±18	0.28±0.08	2.6±0.9		75.7±9.6	8.1±5.0		51.3±7.2	0.03±0.01	2.5±1.8
2000	Silver pomfret	97±40	0.19±0.16	2.7±2.7	Maoxia shrimp	131±12	6.6±5.1	Ark	72.7±10.9	0.02±0.00	6.7±6.5
2001		65.4±23.0	0.10±0.04	2.1±0.7		112±96	27.8±12.5		44.2±32.2	0.03±0.00	2.1±0.7
2000	Yellow crucian carp	100±22	0.12±0.03	3.4±2.9				Scallop	45.1±0.2	0.04±0.00	1.5±0.1
2001		66.8±20.2	0.09±0.02	7.1±6.7					47.3±22.9	0.04±0.01	4.1±1.1
2001	Hairtail	103±12	0.13±0.02	1.2±0.6				Cuttlefish	31.6±16.0	0.01±0.01	2.8±2.1

Algae and little plankton (Bq/kg)		^{40}K	^{90}Sr (10^{-2}Bq/kg)
Laver (dry weight)	2000	1166±501	133±102
	2001	1004±549	11.4±6.2
Japanese kelp (dry weight)	2000	1128±116	210±34
	2001	1722±88	55.8±59.6
Little plankton (fresh weight)	2000	59.8±4.8	87.5±14.8
	2001	104±77	117±96

	Sea Salt (Bq/kg)			Brine (Bq/L)			
	^{40}K	^{90}Sr	K (g/kg)	^{40}K	^{90}Sr (mBq/L)	K (g/L)	^{3}H
2000	20.1±8.4	48.4±4.8	0.84±0.15	179±28	20.5±2.8	7.44±2.56	1.89±0.45
2001	38.7±3.6	20.2±1.8	4.28±1.20	257±123	4.3±0.5	11.8±4.0	1.23±0.10

Marine indicating organism (Bq/kg)		^{40}K	^{7}Be	^{137}Cs	^{90}Sr
Common blue mussel	2000	31.3±0.8	<0.3	0.04±0.01	0.50±0.01
	2001	41.0±12.4	0.7±0.5	0.03±0.03	0.30±0.49

Table 2 Comparison of ^{90}Sr in water bodies (mBq/L)

	Rain	Surface	Drinking	Ground-	Seawater

	water	water	water	water	
Summer, 2000	5.5	3.8	4.4	8.8	
Winter, 2000	0.5	2.5	4.0	5.4	2.1
Summer, 2001	1.7	6.5	5.9	9.8	
Winter, 2001	0.2	4.6	7.7	8.8	2.0
Ave.	2.0±2.4	4.3±1.6	5.5±1.7	8.2±1.9	2.0±0.1

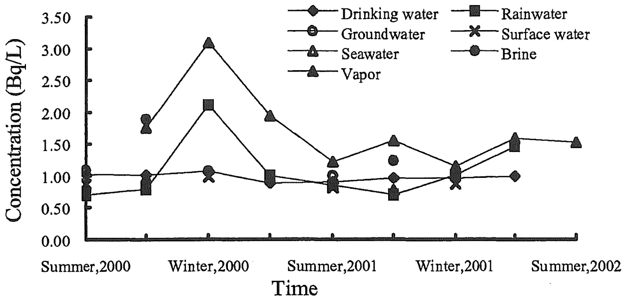

Fig. 1 Concentration of ^{3}H in different water and its change with seasons.

the concentrations of ^{3}H in the environment, contributed by the nuclear weapons tests that took place in the open atmosphere, has diminished substantially as a result of the limited nuclear test ban agreement, but ^{3}H production by nuclear reactors was increasing rapidly. This would reach the lowest level around 1990. However, this estimate was based on the 1970s' expansion speed of nuclear power. In fact, the expansion of nuclear power slowed down heavily due to the catastrophic Chernobyl accident. Thus, the date needed by the environmental ^{3}H concentrations reaching the "valley bottom" will be postponed. As indicated by the monitoring results obtained in recent years by Qinshan Nuclear Power Plant, Daya Bay Nuclear Power Station, Zhejiang Provincial Environmental Monitoring Station and this investigation, the environmental ^{3}H level has been still decreasing. It cannot yet be confirmed whether the level would have reached the lowest point.

2. ^{137}Cs and ^{7}Be in Plant

Figure 2 shows the contents of ^{137}Cs and ^{7}Be in different plants are nearly at the same level during the two years. There are some differences in contents of ^{137}Cs and ^{7}Be respectively, with the highest found in pasture and the lowest in paddy. For ^{7}Be, the content order is: pasture > vegetable > wheat > paddy. For ^{137}Cs, the content order is: pasture > wheat > vegetable > paddy.

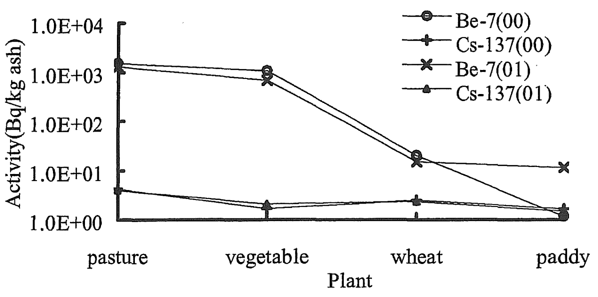

Fig. 2 Comparison of ^{7}Be、^{137}Cs in some main plants

3. ^{137}Cs and ^{40}K in Animal and Animal Products

Figure 3 shows the annual averages of ^{40}K contents in animal and animal product samples between the two years. The content order is pork > chicken > carp meat > beef > milk > egg. The ^{40}K contents in milk and egg are about half of those in beef, chicken and pork.

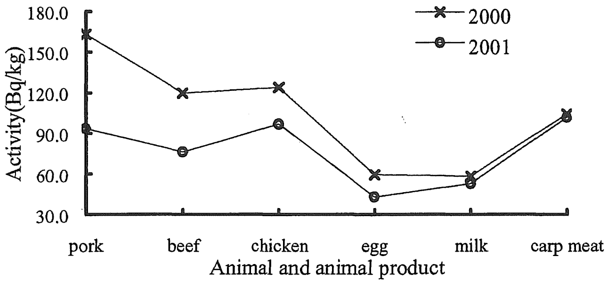

Fig.3 Comparison of ^{40}K contents in animal and animal product

The differences of the ^{40}K contents in different samples are quite distinct between the two years, which may be attributable to sources of samples. The radionuclide contents in animal and animal product are related to the feedstuff. The beef, chicken, and carp samples used in this investigation were all taken from large-sized feedlots and the feedstuff was almost unchanged, so their differences in the nuclide contents were relatively small. However, large-sized hoggery was not found, so the pork samples were all from livestock. The feedstuff used was quite uncertain, so the difference was much larger accordingly.

In addition, the animal's capacity of enriching ^{40}K is different from the capacity of animal products. This would lead to higher contents in animal than in the related animal products.

For ^{137}Cs, there exists the similar situation, namely the contents in animal meat are larger than in related animal products (see **Figure. 4**).

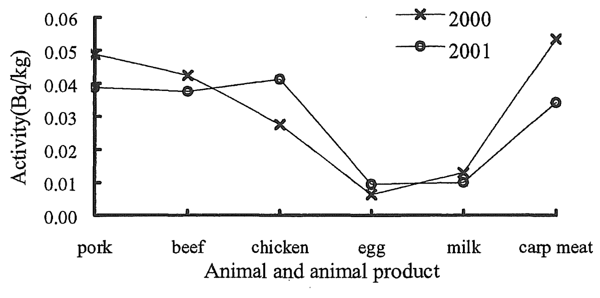

Fig.4 Comparison of ^{137}Cs contents in animal and animal product

4. Terrestrial Indicating Organisms

There was only pine needle used as terrestrial indicating organism in the initial investigation program, and later tea was added in the second year.

Compared with tea, pine needle has a high content of ^{90}Sr, so it can be regarded as the indicating organism for ^{90}Sr. Compared with the other plants, both pine needle and tea have high contents of ^{137}Cs, so they can be regarded as the indicating organisms for ^{137}Cs. However, the due attention should be paid to pasture for it having relative high radionuclide contents.

5. ^{137}Cs in soil, plant and animal

Because all the sampling points for soils, plants and most of animals are located on the same site, there would exists a correlation in food chain among these samples. Therefore, it is necessary to compare their radionuclide contents and discuss the relationship between them.

Table 3 shows the ^{137}Cs contents in the concerned soil, plant and animal samples. Because the measurement results of pasture samples are expressed in dry weight while other plant samples in fresh weight, all the results were expressed in ash weight through mass conversion for the convenience of comparison. In the concerned soil samples, the ^{137}Cs contents are at the same level, while in their corresponding plants, the ^{137}Cs contents are quite different. The ^{137}Cs contents in pasture are much higher than in other plants. This indicates that pasture is able to enrich ^{137}Cs much easier than other plants. In the beef samples taken from cattle mainly eating pasture, however, there are not so high contents of ^{137}Cs as anticipated. It can be found from the foregoing discussions that beef has not as high enrichment capacity for ^{137}Cs as pork and chicken.

Table 3 ^{137}Cs contents in some soil, plant and animal samples

Soil	Paddy field	Vegetable soil	Wheatland	Pasture soil
Content (Bq/kg fresh weight)	4.8±2.1	4.0±1.6	4.8±1.4	4.6±2.1
Plant	Paddy	Vegetable	Wheat	Pasture
Content (Bq/kg fresh weight)	0.009±0.007	0.019±0.010	0.034±0.021	0.17±0.12 (dry weight)
Ash/fresh ratio	0.006	0.010	0.014	0.040 (ash/dry ratio)
Content (Bq/kg ash weight)	1.5±1.2	1.9±1.0	2.4±1.5	4.2±3.0
Animal	Chicken	Pork	Beef	
Content (Bq/kg fresh weight)	0.03±0.01	0.04±0.05	0.04±0.02	

6. Radionuclide Contents in Halobios

Six fishbone samples have been measured for the contents of ^{90}Sr in order to find out the difference between fish and fishbone. The content of ^{90}Sr in fishbone is in the range of 0.059~0.772 Bq/kg (fresh weight), which is 10 times higher than in the corresponding fish except one sample. The contents of ^{40}K and ^{137}Cs in blue-spotted mackerel and ^{90}Sr in yellow crucian carp are relative high.

The contents of ^{40}K, ^{137}Cs and ^{90}Sr in cuttlefish meat are lower than in shellfish. ^{90}Sr content in cuttlefish bone is 3.12 Bq/kg (fresh weight), which is 60 times higher than in cuttlefish meat. It suggests that cuttlefish bone can strongly enrich ^{90}Sr.

7. Marine Indicating Organism

At first, gulfweed was used as the marine indicating organism in this investigation. Because gulfweed was difficult to collect, common blue mussel was then chosen as the marine indicating organism. Radionuclide contents in common blue mussel and some marine organism are shown in **Table 4**.

Table 4 Radionuclide contents in common blue mussel and some marine organism

Sample	^{40}K (Bq/kg)	^{137}Cs (Bq/kg)	^{90}Sr ($\times 10^{-2}$Bq/kg)
Common blue mussel	38.5±11.2	0.03±0.02	35±41
Conger pike	69.6±18.2	0.06±0.02	
Blue-spotted mackerel	130±18	0.22±0.13	
Silver pomfret	81±35	0.14±0.12	
Yellow crucian carp	84±26	0.10±0.03	
Hairtail	103±12	0.13±0.02	
Rough shrimp	67.6±16.0		58.8±58.7
Maoxia shrimp	121±57		17.2±14.5
Laver	1084±525		74.1±94.8
Japanese kelp	1425±354		132±97
Little plankton	84.4±50.0		86±70

It can be found from **Table 4** that common blue mussel, as a marine indicating organism, is not superior in respect of radionuclide enrichment to other marine organisms. For ^{137}Cs, the content order is: common blue mussel<conger pike <yellow crucian carp <hairtail <silver pomfret < blue-spotted mackerel. For ^{90}Sr, the content order is: common blue mussel <rough shrimp <laver <little plankton <Japanese kelp. Additionally, the further research efforts are needed to confirm whether common blue mussel can be chosen as the marine indicating organism.

IV. Conclusions

- The investigation indicates that there are no significant variations in the radioactivity levels in most of analytical samples between the 2 years.
- Artificial radionuclides ^{134}Cs, ^{58}Co, ^{54}Mn and ^{60}Co were not found in all media we have measured through γ-spectrometry.
- The concentration of ^{90}Sr in groundwater is the highest among all kinds of water in this investigation and the lowest in rainwater and seawater, while the concentration of ^{3}H in vapor is the highest and the lowest in seawater.
- The contents of ^{137}Cs and ^{7}Be in pasture are higher than in other plants. The contents of ^{40}K and ^{137}Cs in animal meat are larger than in the related animal products.
- The content range of ^{90}Sr in fishbone is 10 times higher than in related fish .The contents of ^{40}K, ^{137}Cs and ^{90}Sr in cuttlefish meat are lower than in shellfish. The ^{90}Sr content in cuttlefish bone is 60 times higher than in cuttlefish bone.
- Pine needle can be used as the indicating organism for ^{90}Sr. Both pine needle and tea can be used as the indicating organisms for ^{137}Cs. Compared with some marine organisms used in this investigation, the contents of ^{137}Cs and ^{90}Sr in common blue mussel are significantly low.

Reference

1) Ren Tianshan, et al,. Environmental Tritium Concentrations in Water and Variations in China, Chinese Journal of Radiological Medicine and Protection (in Chinese), Vol.21, No.5, 2001