Radioecological Situation in the Cooling Pond of Chornobyl NPP

Oleg NASVIT

Research Innovative Implementation Enterprise "Stroom", Office "Stroom-Kyiv"
28A, Artema St.,Kyiv, 04053, Ukraine: nasvit@public.icyb.kiev.ua

Abstract

Analysis of the monitoring data on the radionuclides specific activity in water of the Cooling Pond of Chornobyl NPP revealed the regular seasonal cycling of the ^{137}Cs concentration but did not reveal this for ^{90}Sr. It is strongly supposed that this phenomenon is caused by the microbial-controlled seasonal dependant flux of ^{137}Cs from the bottom sediments to the water. Analysis of the ^{137}Cs profiles in deep water sediment (silt) provides additional forcible argument in favour of this supposition.

The data obtained during radioecological survey carried out in August 2001 proved that on the eve of its decommissioning the Cooling Pond of Chornobyl NPP entered the stage of stabilisation of radioecological situation. The amounts of major radionuclides accumulated in the bottom sediments of the Cooling Pond are estimated to be 4,400, 650 and 18 Ci for ^{137}Cs, ^{90}Sr and ^{241}Am, respectively. About 70% of ^{137}Cs, 50% of ^{90}Sr and 80% of ^{241}Am that are present in the Cooling Pond will remain under the water after the water level will have been dropped down to the natural elevation. The data on the concentration of ^{137}Cs and ^{90}Sr in different fish and water plant species as well as in bivale mollusc Dreisena are also presented.

1. Introduction

The Cooling Pond of the Chornobyl Nuclear Power Plant, which is situated in the northern part of Ukraine, is an artificial reservoir, created on the right-bank flood plain of Prypiat river for cooling of four reactor units of NPP. Banks of the Cooling Pond are formed by both an above-land terracing of the river and a protecting dike of 25 km in length. The diked-off area includes river bed, old arms and lakes. The water surface area of the Cooling Pond is about 22 km^2, volume – about 0.15 km^3, length – 11 km, and width – 2 km. The mean depth of the Cooling Pond is 6.6 m, maximum depth – about 18 m, and water elevation 5-7 m over the Prypiat river level. To compensate water losses due to leakage and evaporation, water is permanently pumped from Prypiat river to the Cooling Pond.

After a devastating accident happened at Chornobyl NPP on 26 April 1986, a large amount of radioactive materials released from the completely destroyed Unit #4 caused radioactive contamination of the environment, especially severe in the vicinity of NPP.

The Cooling Pond on the bank of which Chornobyl NPP is situated was contaminated by radioactive fallout, mainly dispersed fuel particles that felt directly on the water surface. In addition, 5,000 m^3 of heavily contaminated water from the reactor basement was released to the Cooling Pond, and during the decontamination activities a massive amount of soil removed from the nearby sites with high level of

Table 1. ^{137}Cs and ^{90}Sr in components of Cooling Pond ecosystem in Summer 1986, kBq/kg f.w., kBq/l [2].

Component	^{137}Cs	^{90}Sr
Water, up to	1.7	0.05
Bottom sediments	10-380	1-100
Aquatic plants	50-180	15-45
Molluscs	18-35	35-60
Fish (carp)	100-260	2-3

radiation was also placed in the Cooling Pond [1]. According to various estimates, the Cooling Pond in total received from 2,200 to 13,000 TBq (60 to 360 thousands Ci) of radionuclides [1, 2, 3]. Specific gross-beta activity of water in the beginning of May, 1986 was about 10^5 Bq/l, mainly due to ^{131}I and other short-living radionuclides. Radioecological investigations performed in Summer, 1986, showed high levels of ^{137}Cs and ^{90}Sr specific activity in all components of the Cooling Pond ecosystem (Table 1).

During 1986 due to physical decay short-living radionuclides gradually eliminated from the spectrum of radioactive contamination of the Cooling Pond ecosystem, and about 95-98% of remaining radioactivity, including long-living nuclides such as ^{137}Cs, ^{90}Sr, $^{238, 239, 240, 241}$Pu and ^{241}Am settled to the bottom due to processes of sedimentation. After survey of bottom sediments had been carried out in 1989 and 1991, the estimates was done of the inventory of long-living radionuclides in the Cooling Pond. According to these estimates the Cooling Pond contains about 170 TBq (4,600 Ci) of ^{137}Cs, 35 TBq (950 Ci) of ^{90}Sr and 0.8 TBq (22 Ci) of ^{239,240}Pu [1].

In December 2000, the Unit #3, the last operating one at Chornobyl Nuclear Power Plant was shut down. In some years Chornobyl NPP will not need the Cooling Pond anymore. Considering the future fate of the Cooling Pond and respective necessary actions, one should take into account the followings: from one hand, keeping the existing water level is rather expensive and, from the other hand, leaving the Cooling Pond without pumping of water from the river would drain a large part of bottom and may cause radiological problems for personnel of the industrial site due to wind resuspension of dried sediments containing transuranics.

The problem of possible resuspension of bottom sediments is being studied now in a number of projects. But another side of the problem, i.e. what will happen to water bodies, which will remain on the place of the Cooling Pond after it will have been drained, is still without proper attention of radioecologists. Assessment of the future state of the Cooling Pond is possible only on the basis of comprehensive description of the existing situation and using of validated models of radionuclides migration which take into account specificity of biological processes during the transition period.

The objectives of this work are to summarise the existing information on the levels of radioactive contamination of the components of the Cooling Pond ecosystem, to reveal probable processes governing these levels of radioactive contamination, and to provide the information to forecast the future radioecological situation in this water-body.

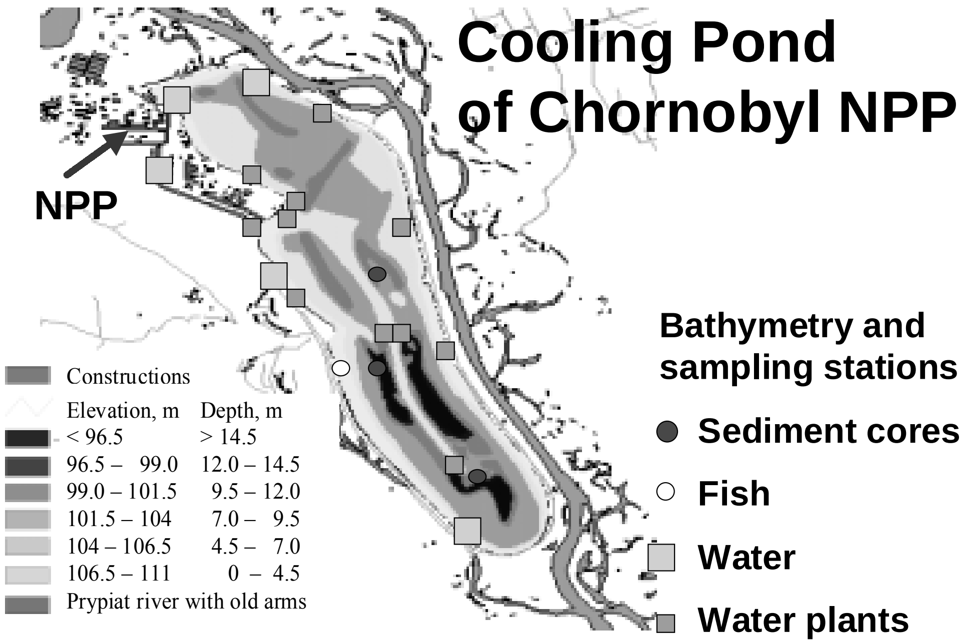

Fig. 1. Scheme of the Cooling Pond of Chornobyl NPP with bathymetry and sampling stations location.

2. Materials and Methods

2.1. Water samples

Water samples from the Cooling Pond were taken at the regular intervals since the beginning of 1987 within the program of radioecological monitoring of the exclusion zone. During 1987 samples were taken 4 – 6 times per month, in 1988 – 2 times per month, since 1989 and up to now – monthly. The number of sample sites varied from 5 to 10. During 1987 – 1992 from 1 to 10 litres were sampled for total (without separation for suspended and dissolved fractions) ^{137}Cs and ^{90}Sr activity determination. In 1987 – 1988 direct gamma-spectrometric measurements of water samples were performed. In 1989 – 1992 ^{137}Cs was collected by sorption on FEZHEL (potassium-iron ferrocyanide) at natural pH without prior filtration of the water.

Since 1993 surface water samples are taken at 5 sites shown in Fig. 1. On each site a sample of 20 l is taken. In the laboratory sample is filtered through paper filter (blue band), and dissolved ^{137}Cs is collected by sorption on FEZHEL at natural pH. Filter and sorbent are measured separately for determination of associated with suspended matter and dissolved ^{137}Cs.

Since 1997 the radiochemical isolation of ^{90}Sr from water by the sulphate method [4], which was used since the beginning of regular observations, was modified and collection by sorption (complexation) on VS-15M1 (synthetic selective sorption fibre material with grafted macro cycles groups) at natural pH was introduced at the first stage [5].

2.2. Bottom sediments samples

Samples of bottom sediments were collected in July and August 2001 with ДТШ-3 (DETESHA-3) corer at water depths 0 – 6 m, and a weighted gravity coring rig with 70 cm transparent cylindrical nozzle was used at water depths more than 6 m. For investigation of the depth distribution as well as the total inventory of ^{137}Cs in deep-water sediments, cores (5.8 cm diameter and up to 70 cm long) were cut on site into slices as a rule 5 cm thick, but in a number of cases the slice thickness was adjusted to observed natural boundaries of core material with different properties.

Cores of shallow sediments (water depth less than 6 m), represented by sands, silted sands and transformed primary soils were cut into three layers: 1 cm top, 1 cm bottom, the rest. All sediment samples were analysed for bulk density, content of water and radionuclides.

2.3. Biotic samples

Biotic samples were taken in August, 2001 during radioecological survey of the Cooling Pond.

Fish was sampled by fishing net. All fishes were caught at the same site shown in Fig. 1. Each fish was weighted and measured in length. About 100 g of fresh muscle tissue was dissected from each fish and packed into plastic vials for ^{137}Cs measurements. Selected samples were taken for ^{90}Sr analysis. Scales were taken from each fish for determination of age.

Dreissena molluscs were collected from concrete hydrotechnical constructions with scraper or from bottom (3-7 m depth) with dredger together with sediments sampling, and ground for analysis.

Plants were collected in the littoral zone at 11 sites around the Cooling Pond. The above-sediment parts of plants were sampled. Plant tissues were rinsed, air-dried and ground for analysis. The fresh and dry weight was determined.

Seston samples were collected with phytoplankton net (gauze Nr. 76) in pileup of planktonic algae, mainly blue-green. Samples were air-dried, weighted and ground for analysis.

Samples of invertebrates, plants and seston were measured for ^{137}Cs. Selected samples were taken for ^{90}Sr analysis.

2.3. Radioactivity measurements.

Gamma-spectrometry was performed using Ge(Li) detector and MCA. Beta-measurements were performed using beta-spectrometer AKC-1 and low-background counting devises UMF-1500M.

3. Results and discussion

3.1. Water

Annually averaged specific activities of total ^{137}Cs and ^{90}Sr in water of the Cooling Pond are presented in Fig. 2. In general this data is in good agreement with the results presented earlier for 1986 – 1995 [2, 6]. It is well known that ^{137}Cs and ^{90}Sr content in water is influenced by several main processes. Among them the interaction in a system "water-suspended matter-bottom sediments" is of major importance for water-bodies with medium and high level of biological productivity and/or high level of suspended particles concentration. During the first year after the accident the observed fast declining of ^{137}Cs and ^{90}Sr specific activity in water was caused by their trapping with suspended matter and settling to the bottom. Slowing down of declining for ^{137}Cs and even increasing of concentrations of ^{90}Sr observed in

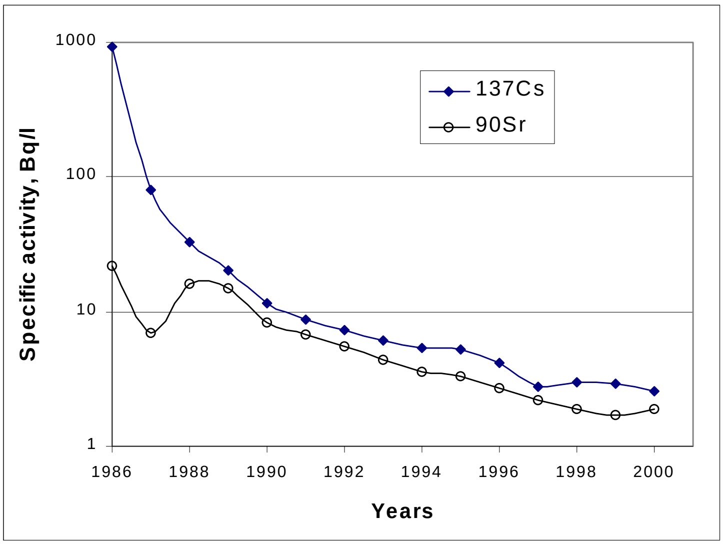

Fig. 2. Total ^{137}Cs and ^{90}Sr in water of the Cooling Pond, annually averaged.

the third and fourth years were caused, probably, by the additional release of these radionuclides to water from the fuel particles due to their destruction. From 1990 to 1997 almost equal declining of both radionuclides was observed and since 1997 both radionuclides tend to have about stable concentration. Some minor discrepancies in figures and declining rates between ^{137}Cs and ^{90}Sr specific activities for 1992-1995 presented in publications [2, 6] and in Fig. 2 could be explained by the fact that the latter was provided on the basis of more regular observations.

Monthly averaged specific activities of total ^{137}Cs and ^{90}Sr in water of the Cooling Pond are presented in Fig. 3. As it could be seen from Fig. 3 regular observations of ^{137}Cs in the Cooling Pond water providing the possibility of the analysis on monthly basis were started in late 1986 (actually in December) and of ^{90}Sr – in spring 1988, although this analysis has never been done before. It was just noticed that higher specific activities of ^{137}Cs in water of the Cooling Pond were observed usually in summer and during the year the variations with a factor of 2-3 were observed. If one get a look of plots presenting monthly averaged specific activities of total ^{137}Cs and ^{90}Sr in water of the Cooling Pond on the background of grid-lines marking the beginning of the year (Fig. 3), he could assume the presence of regular seasonal changes of at least ^{137}Cs concentrations.

To reveal the seasonal regularities the period of 1993 – 2000 was taken as less influenced by general processes of radionuclide concentration reduction. For this period the detailed analysis of seasonal

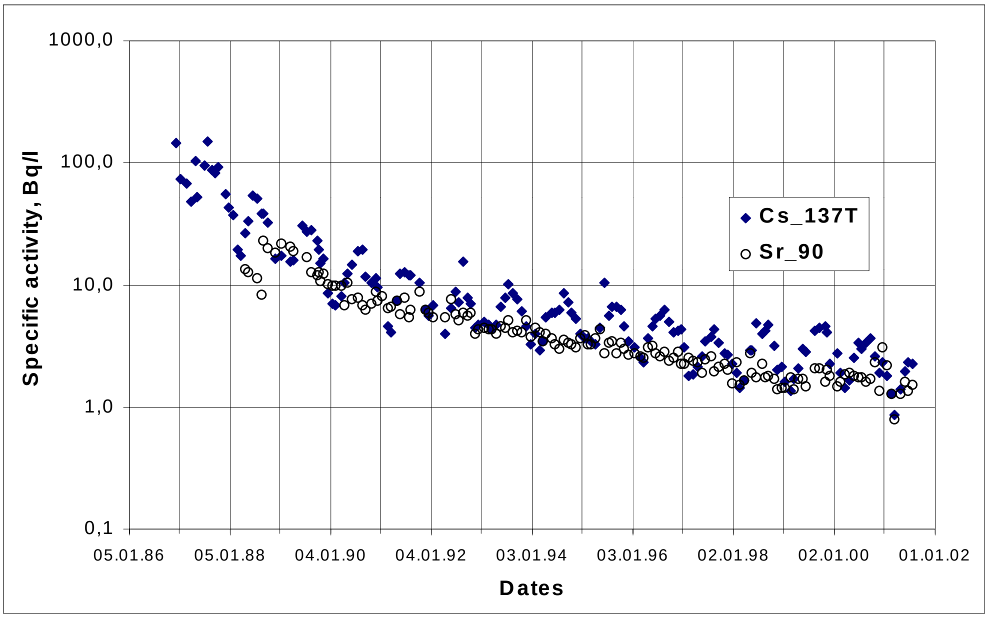

Fig. 3. Total ^{137}Cs and ^{90}Sr in water of the Cooling Pond, monthly averaged.

behaviour of the total ^{137}Cs and ^{90}Sr specific activity in water was performed and the general trends were found (Fig. 4). Using the regression lines in Fig. 4, the seasonal component of specific activity changes was extracted (Fig. 5). The relative units in chart represent the ratios of the actual monthly data to the respective calculated values (regression lines) and the confidence intervals represent the standard deviation values.

As it could be seen from Fig. 5, ^{90}Sr does not tend to show the seasonal changes. To the contrary, ^{137}Cs strongly tends to show the regular seasonal changes with minimum values in February-March and maximum – in June-September with August values exceeding that of February by a factor of 2.5.

There are two main ideas of explanation of the revealed phenomenon. The first is the presence of seasonally dependant flux of ^{137}Cs to water from the bottom sediments. The second is the seasonal development of plankton organisms that would influence the total ^{137}Cs specific activity in water. To check the possible influence of the seasonal plankton development the seasonal behaviour of a ratio of suspended to total ^{137}Cs in water was studied. It was found that the highest contribution of suspended ^{137}Cs

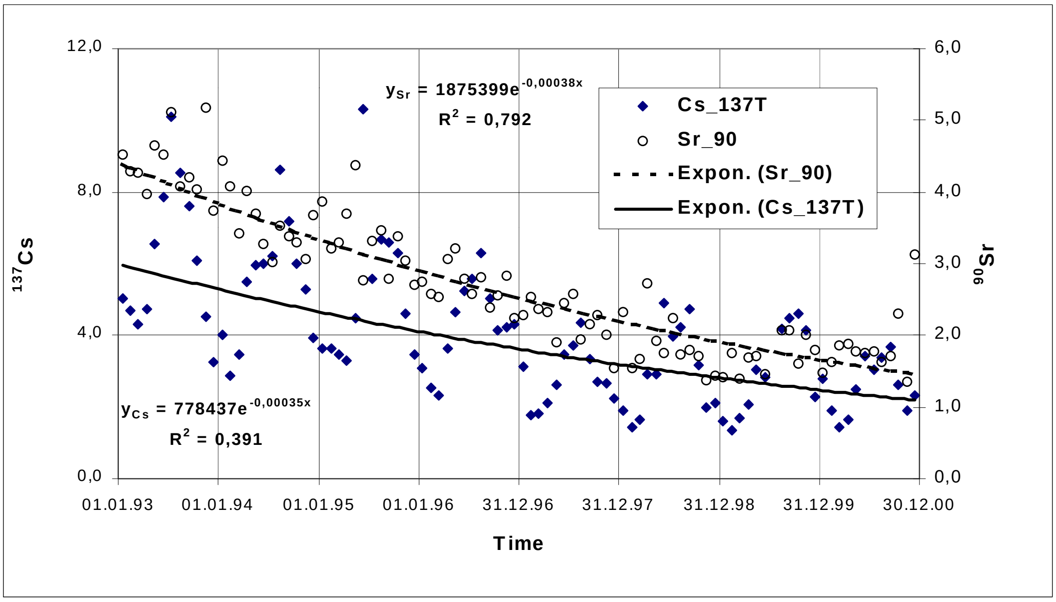

Fig. 4. Total ^{137}Cs and ^{90}Sr in water of the Cooling Pond in 1993 - 2000, monthly averaged, Bq/l.

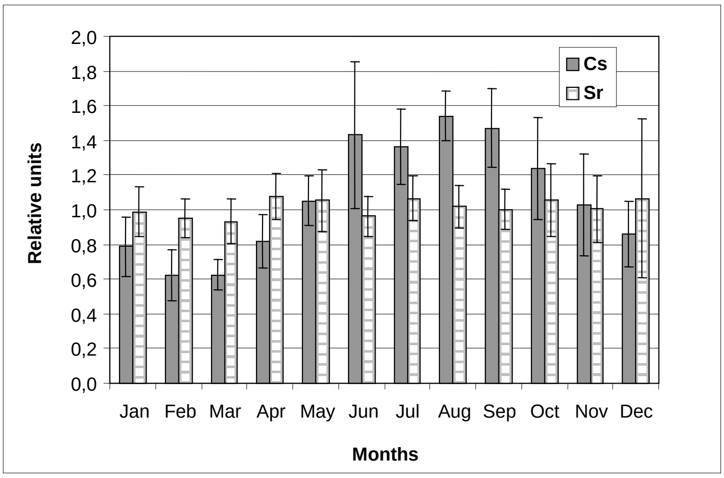

Fig. 5. Seasonal behaviour of total ^{137}Cs and ^{90}Sr in water of the Cooling Pond.

is observed in May and comprise about 25% of total ^{137}Cs in water with mean seasonal value less than 15% (Fig. 6). So, the ^{137}Cs fraction associated with seston, being the composition of plankton organisms, organic detritus and mineral particles, does not exceed 25% of total ^{137}Cs in water and could not provide seasonal deviations with a factor of 2.5. That is why the presence of seasonally dependant flux of ^{137}Cs from the bottom sediments is strongly supposed.

Meanwhile, the seasonal cycling of ^{137}Cs concentrations in water peaking in winter or summer has been reported to take place in several lakes [7-11]. In each study this phenomenon was attributed to dissolution of ^{137}Cs from the bottom sediments by ion exchange with ammonium ions whose elevated concentrations are observed under anoxic conditions. It was proved by field measurements and laboratory experiments that microbially produced NH_4^+ is the most important in release of ^{137}Cs from sediments into lake water. Nowadays the linkage between Cs and nitrogen transfer, which is mediated by microorganisms, is considered to be a rather general phenomenon in freshwater systems rich in organic matter [11]. In order to clarify the real mechanism about the ^{137}Cs seasonal cycling in water of the Cooling Pond, the experiments should be planed to check the distribution of ammonium ion concentrations in water column and sediment cores.

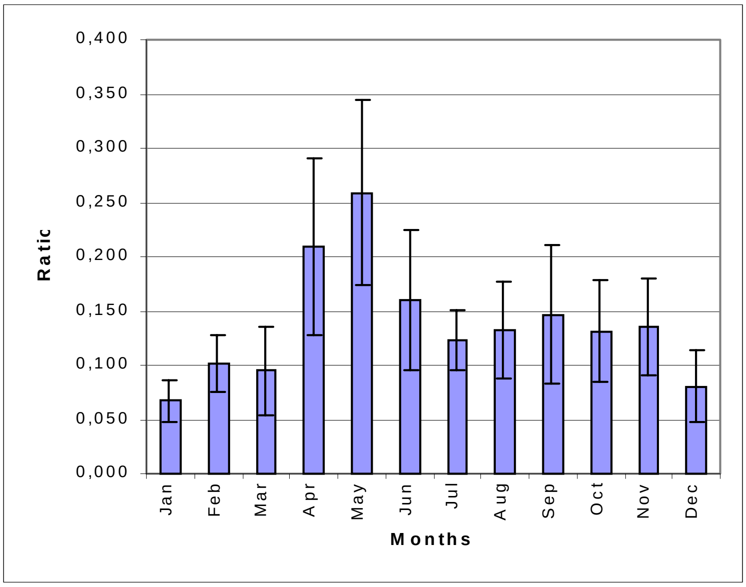

Fig. 6. Seasonal behaviour of ratio of suspended to total ^{137}Cs in water of the Cooling Pond.

3.2. Bottom sediments

Before the accident the last comprehensive hydrological survey of the Cooling Pond bottom sediments was performed in 1985 by the Institute of Hydrobiology [12]. Primary soils (sand loam and loam) of different stage of transformation were found to meet at water depths of 3 to 8 m and to be dominant at depths of 4-7 m. Sands of different extent of silting were met to the water depths of 12 m, and were found to be dominant at depths of less than 5 m and 6-10 m (Fig. 7). Bottom areas with depths more than 10 m were occupied by silts.

It was also found that two parts of the Cooling Pond that were sequentially turned into operation in 1976 and 1982, and were 9 and 3 years old in 1985, respectively, had different dependencies of silt layer thickness and annual sedimentation rate upon the water depth to the bottom (Fig. 8). The younger part had 1.5 times less average thickness of the silts layer and 2-3 times more sedimentation rate, being maximal of about 12 cm/year (the thickness of last-year layer of sediments) [13]. The last finding was very important for understanding of the distribution of radionuclides over bottom sediments of the Cooling Pond after the accident.

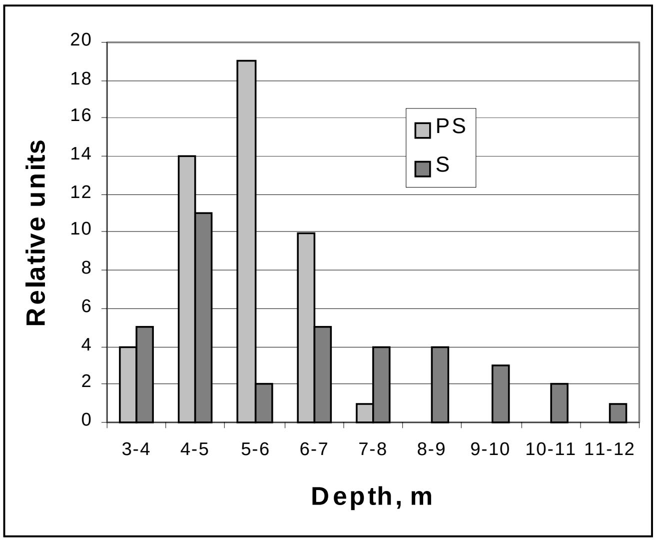

Fig. 7. Depth distribution of primary soils (PS) and sands (S) at the bottom of Cooling Pond, 1985.

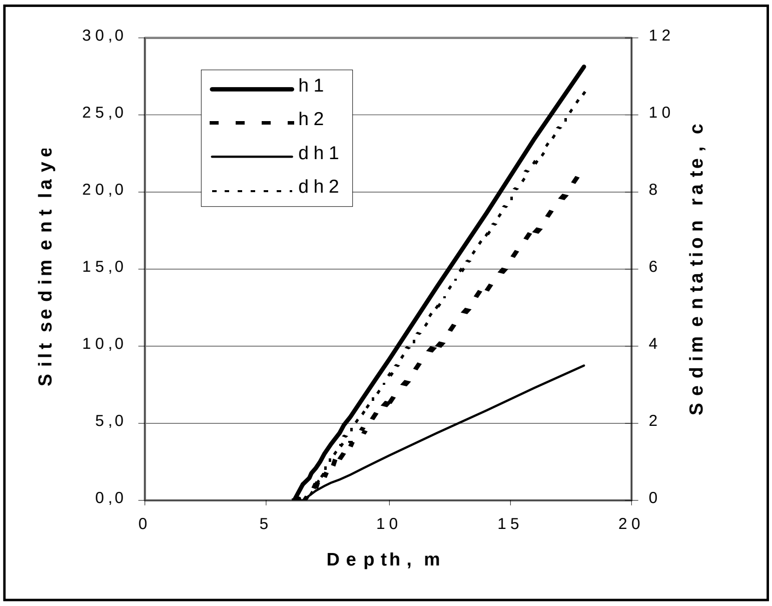

Fig. 8. Average silt sediment layer (h) and annual sedimentation rate (dh) at different depths of the first (1) and second (2) parts of the Cooling Pond [13].

Table 2. Specific activity of the top layer of deep-water sediments, kBq/kg d.w.

	^{137}Cs	^{90}Sr	$^{239,240}Pu$	^{238}Pu	^{241}Am
Average	470	41	1.4	0.67	2.0
Maximal	580	110	2.4	1.2	4.1

The bottom sediments surveys carried out in 1989, 1991, 1999 were concentrated mostly on the radiological issues and did not contribute a lot to the understanding of development of different soils distribution over the bottom of the Cooling Pond with respect to different depths.

Investigations carried out in 2001 revealed that primary soils did not degrade completely and still could be recognised by the presence of roots remains. In most cases, however, being different from the situation in 1985, wide areas of primary soils are covered by layer of silt (as a rule thin 1 – 1.5 cm, and sometimes up to 6 cm), in many cases mixed with Dreissena bivalve shells. Stable silt accumulation is observed at depth more than 10 m on the older part of the Cooling Pond, and at more than 11 m on the younger part.

Deep-water silt sediments present the highest specific activity of radionuclides. In the top layer of this sediment represented by recently settled materials the specific activity of all radionuclides other than ^{90}Sr varies insignificantly over the whole area (Table 2). For ^{90}Sr the difference was observed with a factor of 10.

In the areas of stable silt accumulation the density of radioactive contamination was generally found to correlate with the thickness of accumulated silt. That is why it is not surprising that the highest densities of ^{137}Cs contamination, up to 4,000 Ci/km^2 or 150 MBq/m^2, were found in the younger southern part of the Cooling Pond where higher annual sedimentation rates were observed in 1985. The most active samples of silt with ^{137}Cs specific activity of about 1.4 MBq/kg d.w. were taken also in the southern part. At water depths of 11-14 m the most contaminated layer of 1986 is covered with several tens centimeters of more recent silt sediments (Fig. 9). The most recent top layer within 5-6 cm has more contamination than the next deeper one (Fig.9) that is against the general tendency of decreasing with time of contamination level of the settling material. Taking into account the seasonal variations of ^{137}Cs concentrations in water and our considerations on the possible reasons of that, the observed picture might be explained by the presence of flux of ^{137}Cs from deeper layers of sediment to upper and then to water. In upper layers of sediment the flux of cesium meets different conditions (less anoxic, less ammonium concentrations in the interstitial water) and is being trapped by the sediment particles. These assumptions should be checked in future

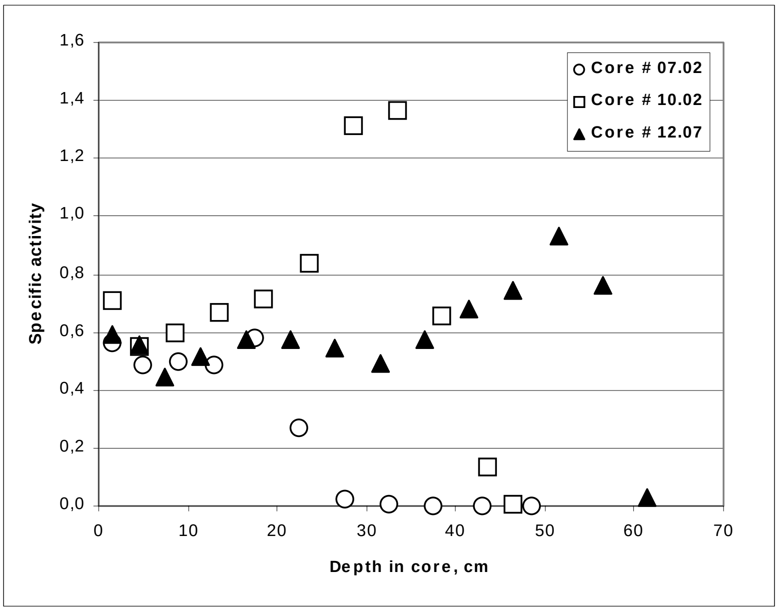

Fig. 9. ^{137}Cs specific activity in bottom sediments (silts), MBq/kg d.w.

Table 3. Inventory of radionuclides in the bottom sediments of the Cooling Pond, after [14].

Radionuclides	Total content in the bottom sediments, Ci	Total content in the bottom sediments in a part which will remain under water, Ci
^{137}Cs	4,400	about 3,000
^{90}Sr	650	313
$^{239, 240}Pu$	14	11
^{238}Pu	7	n.e.*
^{241}Am	18	n.e.*

* - n.e. means not estimated.

investigations.

On the basis of investigations carried out in 2001 the whole inventory of radionuclides in the Cooling Pond was estimated as well as the part of area which would remain under water after the water level would had been dropped down [14]. This gave us the possibility to assess the minimal activity of radionuclides (without taking into account transsedimentation processes) that will remain under water, (Table 3).

So, after the water level in the Cooling Pond will have been dropped down to the natural elevation, about 70% of ^{137}Cs, 50% of ^{90}Sr and 80% of $^{239, 240}Pu$ will remain under water and will form the new radioecological situation in a number of water-bodies on that territory.

3.3. Biota

Fish: Average ^{137}Cs and ^{90}Sr specific activity in fish muscles is presented in Table 4. As it is seen from Table 4, the highest specific activity of caesium is observed for typical predatory species, perch and pike-perch. Some less activity is observed for omnivorous sabre carp and freshwater catfish that tend to feed also on other fish. Typical omnivorous species goldfish and lake catfish (the last being facultative predator, but in the Cooling Pond feeding upon periphyton and detritus [15]) are the next in this downward row. The lowest concentrations are found in silver bream, rudd, roach and bream which feed upon benthos and plankton organisms and vegetation. Some more concentration observed in chub, being omnivorous and facultative predator, and silver carp, which feeds upon plankton.

Almost the same row (sequence of species) was reported for ^{137}Cs specific activity in fish of the Cooling Pond in 1999 [15], the only exclusion was the highest concentration observed in freshwater catfish. It should be noticed that not only the sequence of species but also the absolute values of caesium concentrations were about the same in respective species.

On the contrary to caesium, concentration of ^{90}Sr in fish muscles is rather low, being minimal in lake

Table 4. Average ^{137}Cs and ^{90}Sr specific activity in fish muscles, August 2001, Bq/kg f.w.

Fish species	**^{137}Cs**	**^{90}Sr**
Silver bream	2,400	6.6
Rudd	2,750	10.9
Roach	3,100	4.3
Bream	3,100	-
Chub	3,850	-
Silver carp	3,900	9.5
Lake Catfish	5,100	1.7
Goldfish	5,800	5.3
Sabre carp	6,300	15.3
Freshwater Catfish	8,100	-
Pike-perch	11,800	2.3
Perch	18,100	2.7

catfish and predatory species and maximal in mainly planktotrophic species (Table 4).

Molluscs: Periphyton and benthos bivalve molluscs Dreissena were studied. Average ^{137}Cs concentration was about 2,600 Bq/kg f.w. with the range from 270 to 9,100 Bq/kg f.w., being the highest at the end of directing dyke, i.e. the most southern part of the habitat. Average ^{90}Sr concentration in Dreissena was about 760 Bq/kg f.w. with the narrower range from 610 to 1,140 Bq/kg f.w.

Plants: Macrophytes of the Cooling Pond have rather wide ranges of ^{137}Cs and ^{90}Sr contamination. For each species the ratio of maximal to minimal observed concentration was usually of about 5 to 10 and in some cases up to 80. The narrowest range and respectively the most definite values of ^{137}Cs and ^{90}Sr specific activity were observed for filamentous algae and *Potamogeton pectinatus.* The highest concentration of ^{137}Cs was observed in *Ceratophyllum demersum* - 86.6 kBq/kg d.w. and of ^{90}Sr in *Phragmites communis* – 3.9 kBq/kg (Table 5).

Submerged plants, that are filamentous algae, *Miriophylum spicatum, Potamogeton pectinatus, Ceratophyllum demersum,* have higher levels of ^{137}Cs and ^{90}Sr contamination than semi-water ones (*Phragmites communis).*

Table 5. ^{137}Cs and ^{90}Sr in macrophytes of the Cooling Pond, August 2001, Bq/kg d.w.

Plant species	^{137}Cs		^{90}Sr	
	Range	Mean	Range	Mean
Filamentous algae	7,900 – 12,700	10,800	300 – 1,460	720
Miriophylum spicatum	2,200 – 23,200	8,700	440 – 3,300	1,080
Potamogeton pectinatus	5,030 – 22,600	12,200	640 – 1,160	960
Ceratophyllum demersum	2,100 – 86,600	20,600	320 – 3,260	1,120
Phragmites communis	530 – 6,200	2,340	51 – 3,900	560

Seston: Seston was collected at three stations and measured for ^{137}Cs and ^{90}Sr concentrations (Table 6) and was represented mainly by phytoplankton.

Table 6. Specific activity of ^{137}Cs and ^{90}Sr in seston, August 2001, Bq/kg d.w.

Station	^{137}Cs	^{90}Sr
MOG	10,300	705
PK39	7,685	460
TPD	12,430	1,362

3.4. Dynamics of the ^{137}Cs and ^{90}Sr in the components of Cooling Pond ecosystem

The results obtained together with the previous data [6, 15] gave us the possibility to compile a table for comparison of specific activity of ^{137}Cs and ^{90}Sr in components of the Cooling Pond (Table 7). In comparison to 1995 ^{137}Cs concentration in seston in 2001 dropped down by about a factor of 10, and several times of decrease were also observed for semi-water plants and fish. Real water plants and

Table 7. Specific activity of ^{137}Cs and ^{90}Sr in components of the Cooling Pond, seston and water plants in kBq/kg d.w., molluscs and fish in kBq/kg f.w.

Ecosystem components	1991		1995		2001	
	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr
Seston	300 – 1,000	60 - 270	20 - 140	0.1 - 1.5	7.7 - 12.4	0.7 - 1.3
Water plants	15 - 200	30 - 200				
Semi-water			3 - 25	0.1 - 0.8	0.5 - 6.2	0.05 - 3.9
Real water			8 - 93	1 - 23	2.1 - 87	0.3 - 3.3
Molluscs	1.2 - 6	10 - 25	1.2 - 3.3	2.0 - 6.5	0.3 - 9.1	0.6 - 1.1
Fish			1 - 45	-	2.4 - 18	0.0017 - 0.015

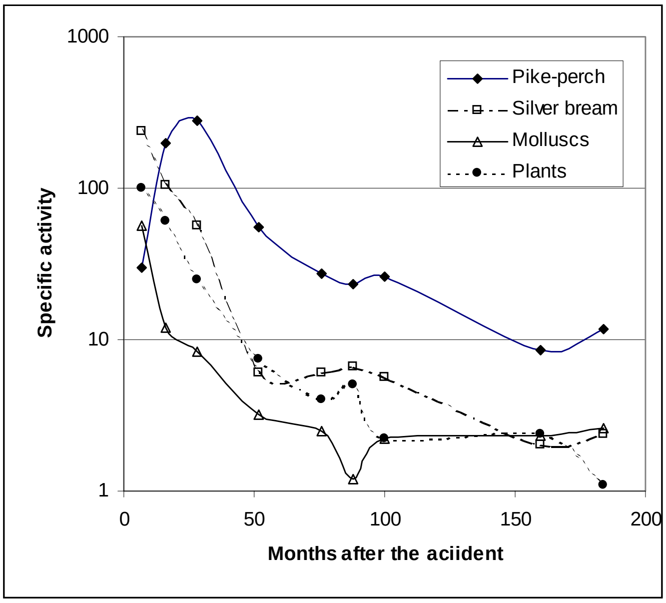

Fig. 10. The dynamics of ^{137}Cs specific activity in the components of Cooling Pond ecosystem, kBq/kg f.w.

molluscs demonstrated the same levels of concentrations as in 1995. As to ^{90}Sr, almost the same as in 1995 or higher concentrations are observed in semi-water plants and seston in 2001. Real water plants and molluscs demonstrate decreasing of ^{90}Sr concentration.

As it could be seen from the Fig.10, during the last 5 years contamination level of molluscs and plants remained almost the same and during the last two years the stabilisation of fish contamination is also seems to have taken place.

4. Conclusions

On the eve of decommissioning the Cooling Pond seems to enter a period of stabilisation of the radioecological situation. General trends of radioactivity reduction are being masked by the seasonal deviations in radionuclides concentration.

It is strongly supposed that seasonal cycling of ^{137}Cs water concentrations are caused by the seasonal dependant flux of caesium from bottom sediments into water. This supposition to be checked in special field studies on the Cooling Pond.

About 70% of ^{137}Cs, 50% of ^{90}Sr and 80% of ^{241}Am that are present at the moment in the Cooling Pond will remain under water after the water level will have been dropped down to the natural elevation.

References

1. Collection and Analysis of Information and Data Related to the Contamination of the Chernobyl Cooling Pond. Final Report. CEC-Contract Number: B7-5350/99/6241/MAR/C2,.GRS mbH, September 2000. 198 p.
2. Modelling and study of the mechanisms of the transfer of radioactive material from terrestrial ecosystems to and in water bodies around Chernobyl. Experimental collaboration project No 3 (ECP3). Final report. EC. Luxembourg: Office for Official publications of the European Communities, 1996 – VIII, 184 pp. EUR 16529.
3. Yegorov Yu.A., Kazakov S.V., Leonov S.V., Staurin N.V. //Radiation state of the Cooling Pond of ChNPP in May 1986. //Chernobyl'88. Reports of the 1st All-Union Scientific-Technical Conference on Overall Results of Elimination of the Consequences of Chernobyl NPP Accident. :Chernobyl, 1989. Vol. 6, P. 76-84. (Rus).
4. Rovinsky F., Iokhelson S., Yushkan E. Methods of the analysis of the environment. Moscow. Atomizdat, 1978. – P. 105-115 (Rus).
5. Ermakov A.I., Malinovskiy S.V., Kashirin I.A., Tichomirov V.A., Sobolev A.I., Rybalka V.B., Serbinovich V.V / Radiostrontium Measurements in Environmental Samples with Using Sorption Materials VS-15-type and Spectrometer on Basis Low-Background Liquid Scintillation Counter / Conference on Low Radioactivity

Measurement Techniques, 18-22nd October 1999, SCK CEN, Mol, Belgium, p.70.

6. Nasvit O., Klenus V., Fomovsky M. The radionuclides content in the hydrobionts of the water-bodies of the exclusion zone. In: Radioecology of water objects of the zone of the Chornobyl NPP accident influence. V. 1. Monitoring of radioactive contamination of the natural waters of Ukraine (review of the studies, performed in 1986-1996), Chornobylinterinform. Kyiv, 1997. P. 215-222 (Rus).
7. Linder G., Greiner I., Grom R., Kaminski S., Kleiner J., Kulikov A., Pfeiffer W., Robbins J.A., Seewald O., Smirnova O., Wilhelm Ch., 1992. Transport of Chernobyl radionuclides in freshwater lakes. Proc. Eighth World Congress of the International Radiation Protection Association, Montreal, pp. 1693-1696.
8. Linder G., Kaminski S., Greiner I., Wunderer M., Behrschmidt J., Schroder G., Kres S., 1993. Interaction of dissolved radionuclides with organic matter in prealpimne freshwater lakes. Verh. Internat. Verein. Limnol.,25: 238-241.
9. Evans D.W., Alberts J.J., Clark R.A., 1983 Reversible ion-exchenge fixation of cesium-137 leading to mobilization from reservoir sediments. Geochim. Cosmochim. Acta, 47: 1041-1049.
10. Comans R.N.J., Middelburg J.J., Zonderhuis J., Woittiez J.R.W., De Lange G., Das H.A., Van der Weijden C.H., 1989. Mobilization of radiocesium in pore water of lake sediments. Nature, 339: 367-369.
11. Kaminski S., Richter T., Walser M., Linder G., Schink B., 1997. Microbially mediated redissolution of cesium radionuclides from the sediment if a shallow eutrophic lake // Freshwater and estuarine radioecology. Proceedings of an International Seminar, Lisbon, Portugal, 21-25 March 1994. Elsevier, 1997. P. 141-150.
12. Study of the radiosensitivity and role of the hydrobions in distribution and migration of radinuclides in the Cooling Pond of Chernobyl NPP and Kiev reservoir.: Final report IHB ASci.UkrSSR on research project № 34. V.1. Kiev, 1985 (Rus.).
13. Hydrobiology of the cooling ponds of thermal and nuclear power plants of Ukraine / Protasov A.A., Sergeeva O.A., Kosheleva S.I. and others; Ac. Sci. UkrSSR. Institute of Hydrobiology.- Kyiv: Naukova dumka, 1991.- 192 p. (Rus).
14. Experimental studies and assessment of the present state of Chernobyl Cooling Pond bottom topography and bottom sediment radioactive contamination. Final report. Task 1. Contract C647/D0426 of 01.02.2001. Center for Monitoring Studies and Environmental Technologies “ECOMONITOR” Ltd., Kyiv 2002, 48 p.
15. Zarubin O.L., Shatrova N.E., Zalisskyi O.O., Derevets V.V., Nazarov A.B. Present radioecological state of the Cooling Pond of ChNPP. / Collection of Scientific Papers of the Institute of Nuclear Researches, #2 (4), 2001.- P. 133-138 (Rus).