Radiotracers in the Black Sea: a tool for marine environmental assessments

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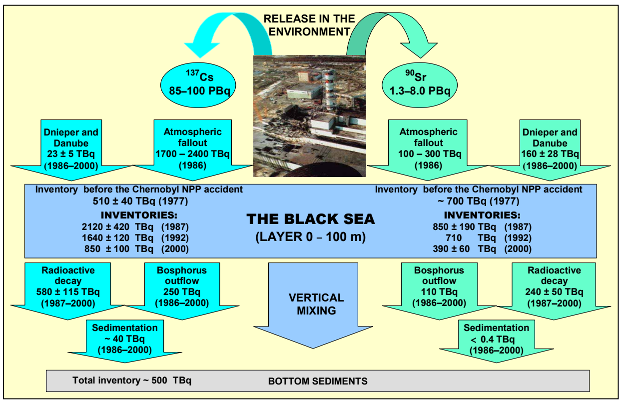
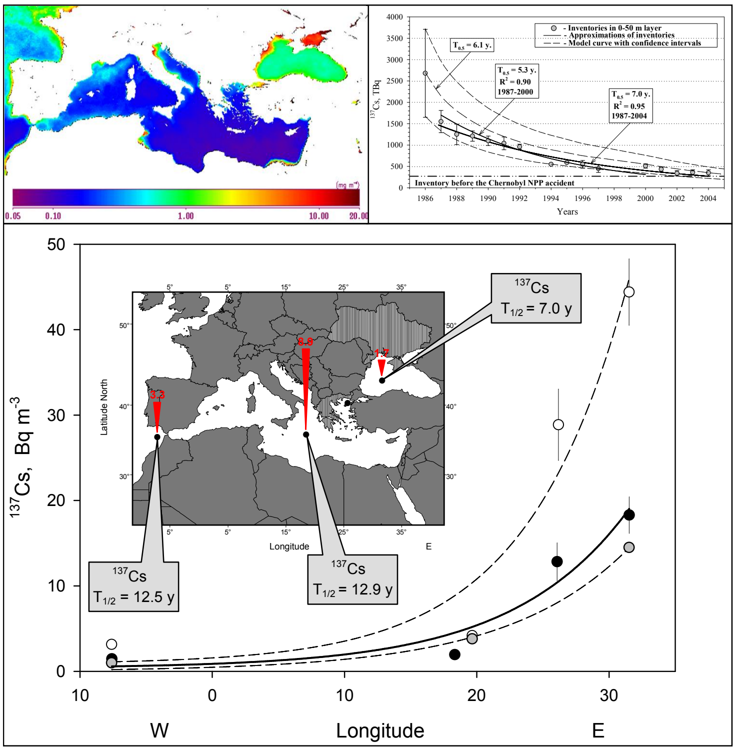
Introduction. Owing to its geographical location, the Black Sea has been one of the marine basins most contaminated with artificial radioactivity. During the pre-Chernobyl period, the main source of radioactive contamination of the Black Sea was the global fallout from the atmospheric nuclear weapon tests, which peaked in 1962 before the 1963 Test Ban Treaty was signed between the main nuclear states. As maximum global fallout was observed within the 40–50^o N latitude band that runs exactly across the Black Sea, this semi enclosed water body received high levels of the fallout radionuclides derived from the atmospheric weapons testing. Being a closest marine body to the Chernobyl site, the Black Sea and its broad drainage areas have received substantial amounts of the long-lived artificial radionuclides, particularly ^{90}Sr, ^{137}Cs, and plutonium isotopes, released into the atmosphere from the damaged nuclear reactor and delivered with the air masses moving south- and westward from the accident area. Besides direct atmospheric deposition, the Black Sea received (and continues to receive) additional radioactive input by river runoff, particularly to its northwestern area from the Danube and Dnieper Rivers. Resulting from contribution of the above-mentioned sources of radioactive contamination of the Black Sea, the ^{90}Sr concentration in its water ranks second after the Irish Sea, and third after the Baltic Sea with respect to ^{137}Cs concentration in seawater.



^{137}Cs and ^{90}Sr balance in the Black Sea after the Chernobyl accident

Overview of results. Extensive radioecological studies performed during the last decades have showed that post-Chernobyl evolution and levels of man-made radioactivity in the Black Sea were governed, except radioactive decay, by the large-scale oceanographic, biogeochemical and ecological processes, which control the self-cleaning of the Black Sea environments against the radioactive contamination: first of all the vertical water mixing, which dilutes the surface radionuclide concentrations, the loss through the Bosporus Strait connecting the Black Sea with the Mediterranean, and sedimentary scavenging of sorption-reactive radionuclides on sinking particles. Because of effects of these factors the initial inventory of Chernobyl-derived radionuclides has decreased abruptly, reaching currently the pre-accident level, except estuarine zones particularly of the Danube and Dnieper Rivers account for 75% of the total river runoff to the Black Sea and 95% of the runoff entering the NW Black Sea. In turn, study of the post-Chernobyl dynamics of radionuclide concentration in different compartments of the Black Sea ecosystem gave a unique opportunity to evaluate a number of hydrological, geochemical, and ecological processes and to trace their long-term changes, achieving eventually an integrated assessment of potential capability of the Black Sea for self-purification against both nuclear and non-nuclear pollutants.

Temporal evolution of ^{137}Cs and ^{90}Sr inventory in the upper Black Sea waters was traced using the time-series data on concentration and vertical distribution of these Chernobyl radionuclides. It was shown that atmospheric fallout of ^{137}Cs deposited on the Black Sea surface during the first days after the Chernobyl accident have been estimated as 1700–2400 TBq that corresponded nearly to 2% of total ^{137}Cs release into the environment and exceeded the pre-Chernobyl inventory in the Black Sea by a factor of 6–10. This initial post-Chernobyl ^{137}Cs inventory has decreased abruptly to 1600 TBq in 1987 due to fast dilution within the upper mixed water masses, and then more gradually to around 500–600 TBq in 1998–2000 and 350 ± 60 TBq in 2001–2004. Unlike ^{137}Cs, the decrease in ^{90}Sr inventory was not monotonic, showing considerable increase in 2001. This may be explained by a larger ^{90}Sr inflow with the river waters due to a stronger runoff occurring in the Dnieper in 1998–1999 and in the Danube River in 1999. The exponential function approximating the time-series measurements of ^{137}Cs concentration in the upper Black Sea water resulted in the apparent half-lives for decrease of ^{137}Cs inventory in the 0–50 m layer between 5.3 years in 1987–2000 and 7.0 years in 1987–2004. The half-life for decrease of ^{90}Sr surface water concentration in the 0–50 m layer is longer, varying from 8.3 years over 1986–2000 to 12.6 years in 1986–2005, suggesting the additional ^{90}Sr input by the river runoff. These values are considerably shorter than those found in the Mediterranean and the Atlantic Ocean, where half-lives for ^{137}Cs in the surface water were 12.9±1.0 and 12.5 ±2.1 years, respectively. The lesser half-life, which was found in the Black Sea, is most likely caused by a faster dilution of ^{137}Cs surface water concentration with riverine waters, as well as by a loss of ^{137}Cs via the Bosporus. The higher self-purification rate of the Black Sea waters has been revealed also for particle-reactive $^{239+240}$Pu, whose surface water concentration measured in 2002 was considerably lower in the Black Sea than in Ionian Sea despite the latter is located much far away from the accident site. As in June 1986 the $^{239+240}$Pu concentration in the surface Black Sea water was of 6.7–16.9 Bq m^{-3}, the half-life of $^{239+240}$Pu may be assessed as 5–8 years that is almost twice shorter than in the Mediterranean. The rapid decrease of $^{239+240}$Pu concentration in the surface Black Sea water is most likely caused by a higher rate of plutonium scavenging on sinking particles in the mesotrophic Black Sea basin, in contrast to oligotrophyc Mediterranean waters.



Longitudinal distribution of ^{137}Cs and $^{239+240}$Pu (red triangular bars) concentration in surface waters of the western Black Sea, Aegean Sea (near Dardanelles), Ionian Sea and in the Atlantic area adjacent to the Gibraltar Strait measured in 2002–2003 (●) in comparison with the post- (○) and pre-Chernobyl (●) data obtained in 1988–89 and the early 1980's, respectively. Numbers above the red bars corresponds to values of $^{239+240}$Pu concentration, mBq·m^{-3}. The left upper panel shows satellite map of annual mean surface chlorophyll concentration for 2002 provided by Dr E. Bosc, MEL-IAEA (the colour coding shows pigment concentration in mg m^{-3}). The right upper panel represents temporal evolution of ^{137}Cs inventory in 0–50 m layer of the Black Sea after the Chernobyl NPP accident

Conclusions. Post-Chernobyl tracing of the Black Sea radioactivity has revealed a higher capability for self-purification of its waters against soluble and particle-reactive radionuclides. As the processes governing decline of their concentration in the Black Sea water (i.e. vertical mixing, dilution with river water, loss via the Bosporus Strait and particle scavenging) are independent of individual chemical and radioactive features of these radionuclides, the obtained half-life values may characterize the self-purification rate of the Black Sea waters against contaminants, both nuclear and non-nuclear having a similar geochemical behaviour.