137-Cs and heavy metals in marine ecosystems- Doses and concentrations (A modeling scenario)

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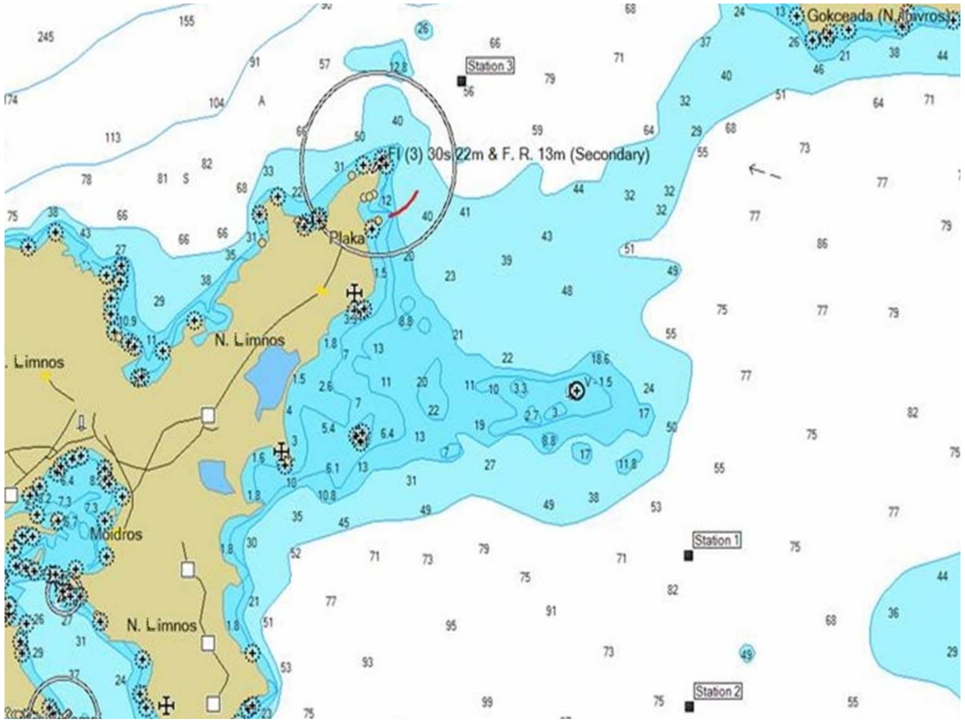
The map of the region



General modeling description

- General deterministic model developed to simulate the time-dependent behaviour of ^{137}Cs in the Aegean Sea.

- Full Navier-Stokes equations for transient, three-dimensional turbulent flow, heat and mass transfer.General form:

$$\partial\left(r_i \rho_i \phi_i\right) / \partial t + div\left(r_i \vec{V}_i \rho_i \phi_i - \Gamma_{\phi_i}\, grad\left(r_i \phi_i\right)\right) = S_{\phi_i}$$

- The model capabilities are demonstrated by applying it at the northeast region of the island of Lemnos, in the NE Aegean Sea.

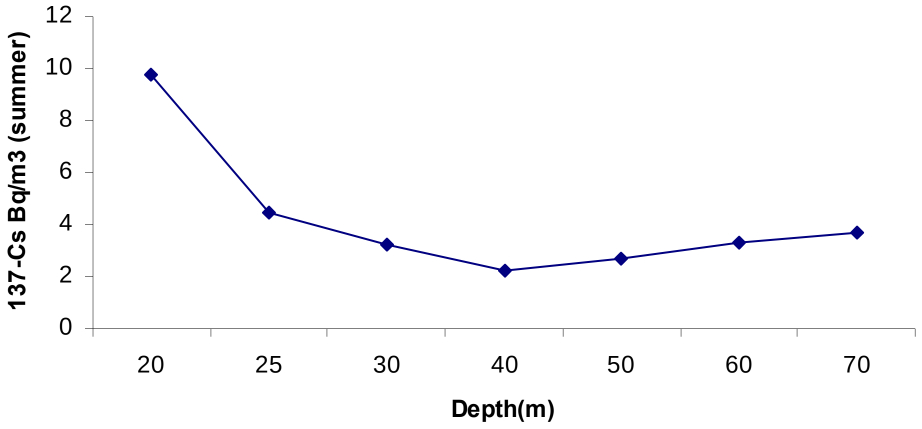
- Solution method:the finite-volume method. IPSA(Interphase Slip Algorithm).

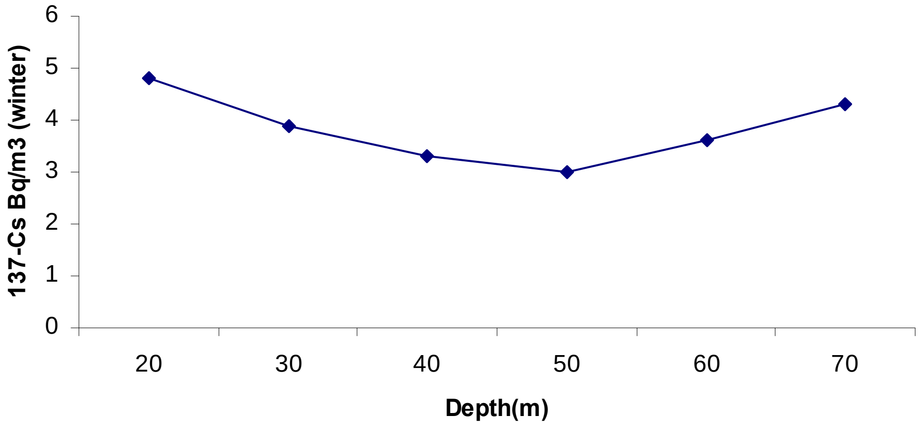
- CFD code PHOENICS.

- RNG (k~ε) turbulence model.

- Hydrodynamic dispersion and turbulence diffusion (sea surface, water column) of ^{137}Cs (activity concentrations Bq m^{-3}). Use of experimental data (*Research NCSR"Demokritos" INT-RP/ERL*)in a limited depth of the water column and horizontal dispersion data, during winter and summer time period . Hydrodynamic dispersion and turbulence diffusion (sea surface, water column) of heavy metals,especially Cu, Ni, Mn. Use of summer period concentrations published data (there exist more published data for heavy metals for this time of the year)
- Estimations of:
- External/Internal/total dose rates received per unify habitats of marine organisms.
- External ,Internal dose rates (human).
- Heavy metals concentrations (fish-human).

The model vertical profiles of 137-Cs





The dose rates in the marine ecosystem of the studied areas (μGy d-1)

^{137}Cs -summer.

Seawater–air intermediate phase	Seawater (Depth 0m)	Seawater (Depth 20m)
$0.5\ 10^{-4}$	$1\ 10^{-4}$	$0.8\ 10^{-4}$

^{137}Cs gamma-radiation -winter.

Seawater–air intermediate phase	Seawater (Depth 0m)	Seawater (Depth 20m)
$0.2\ 10^{-4}$	$0.6\ 10^{-4}$	$0.3\ 10^{-4}$

Natural gamma-radiation in the marine ecosystem in the Greek marine environment.

Seawater–air intermediate phase	**Seawater**
$0.64\ 10^{-4}$ – 0.104	$0.326\ 10^{-4}$ – 0.05

Conceptual model (Polikarpov model)

Uncertainty zone (2.7 10-2 -1 10-1 μGy d-1)
Natural background – zone of radiation well being (0.11 – 14 μGy d-1)
Physiological masking zone (14 – 137 μGy d-1): minor radiation effects at the individual level occur
Ecological masking zone (137 – 10958 μGy d-1): effects of radiation at the population level are detected
Obvious action zone (> 10958 μGy d-1): obvious radiation action (reduction in the number of organisms, elimination of radiosensitive species impoverishment of communities and degradation of ecosystems.

<u>**CALCULATION FORMULAE**</u>

Sediment

D = 9.58 x 10-14As(137Cs) Gy/s

Where : As(137Cs) Activity Concentration of 137Cs in sediment (Bq/kg)

Sediment – sea water intermediate phase

D = 4.79 x 10-14 [As(A)137Cs+ As(B)137Cs] Gy/s

As(A)137Cs Activity Concentration of 137Cs in seawater (Bq/l)

As(B)137Cs Activity Concentration of 137Cs in sediment (Bq/kg)

Sea water

D = 9.58 x 10-14As(137Cs) Gy/s

Where : As(137Cs) Activity Concentration of 137Cs in sea water (Bq/l)

Exposure of swimmers and divers

CALCULATION FORMULA

$D=0.576CE$

D is the dose rate in water
C is the radionuclide concentration including the contribution from the suspended particulate material
E is the photon energy per decay

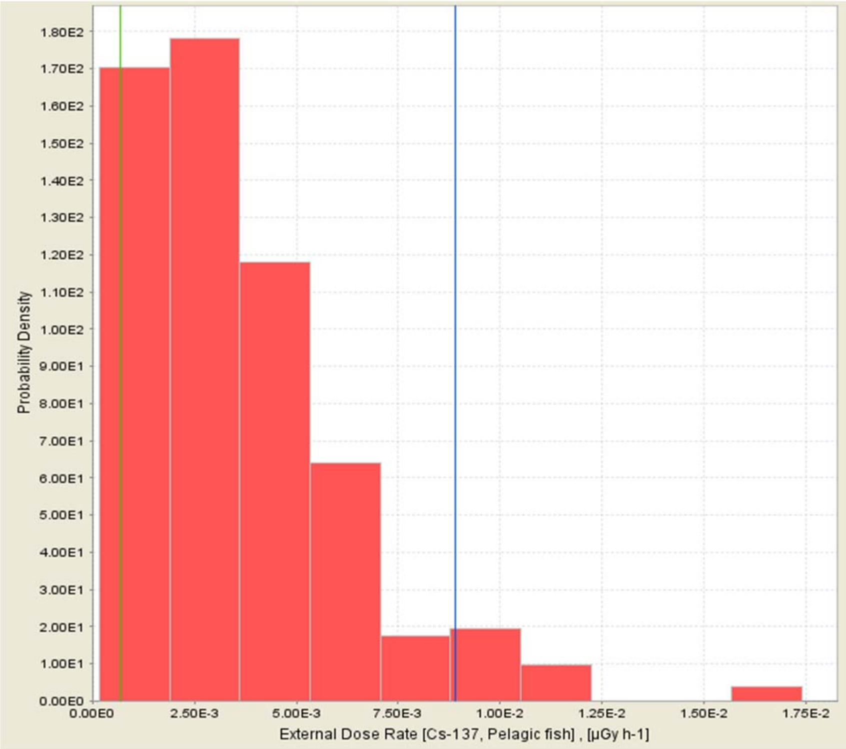
D(summer)=0.005μGy/h

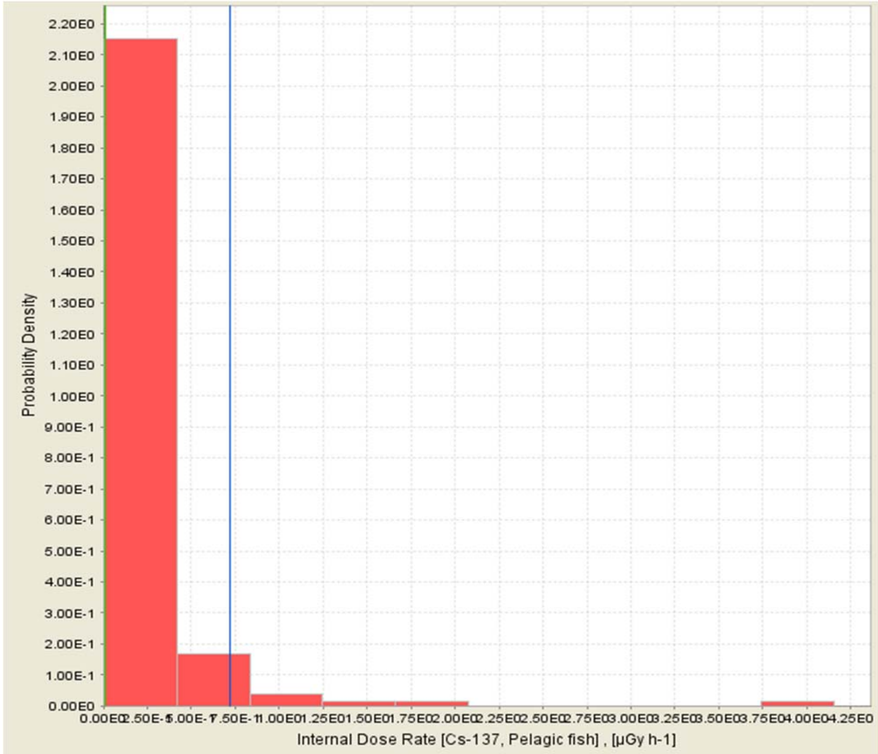
D(winter)=0.003μGy/h

Total Dose Rates in the examined biota

Habitat	Species	*Total dose rates*	*(μGy d^-1^)*
		Summer	***Winter***
Demersal (Organisms live on sediment)	*Arnoglossus laterna*	$284\ 10^{-4} – 295\ 10^{-4}$	$205\ 10^{-4} – 216\ 10^{-4}$
Demersal – Pelagic (Organisms live deep in water)	*Pagellus erythrinus*	$350\ 10^{-4} – 356\ 10^{-4}$	$181\ 10^{-4} – 186\ 10^{-4}$
	Mullus barbatus	$155\ 10^{-4} – 161\ 10^{-4}$	$108\ 10^{-4} – 113\ 10^{-4}$
	Boops boops	$858\ 10^{-4}$	$483\ 10^{-4}$
Pelagic	*Spicara flexuosa*	$109\ 10^{-4}$	$63\ 10^{-4}$
(Organisms live few meters under the water surface)	*Sardina pilchardus*	$970\ 10^{-4}$	$546\ 10^{-4}$
	Trachurus trachurus	$167\ 10^{-4}$	$94\ 10^{-4}$

External,Internal Dose Rates(Pelagic Fish-summer)

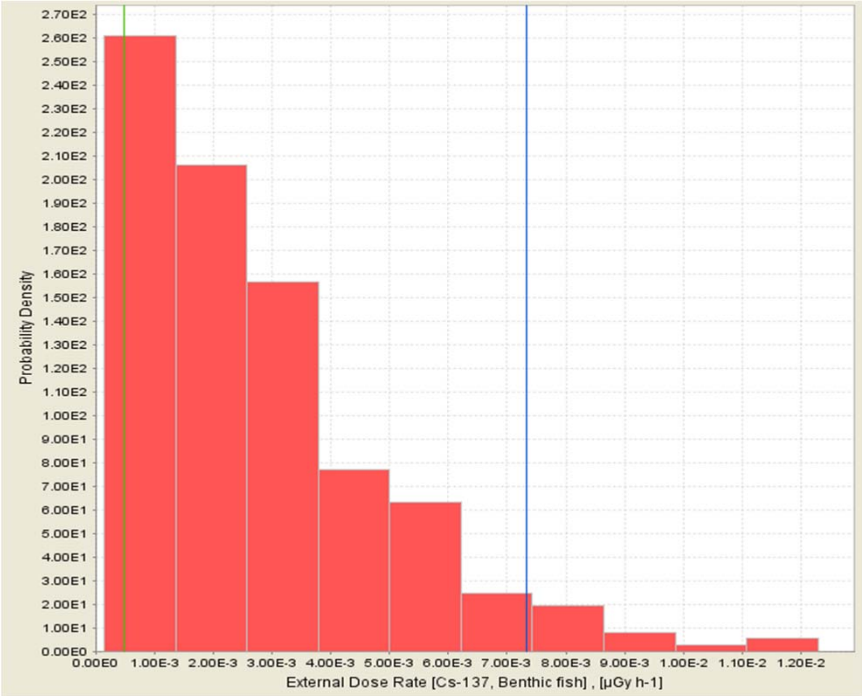


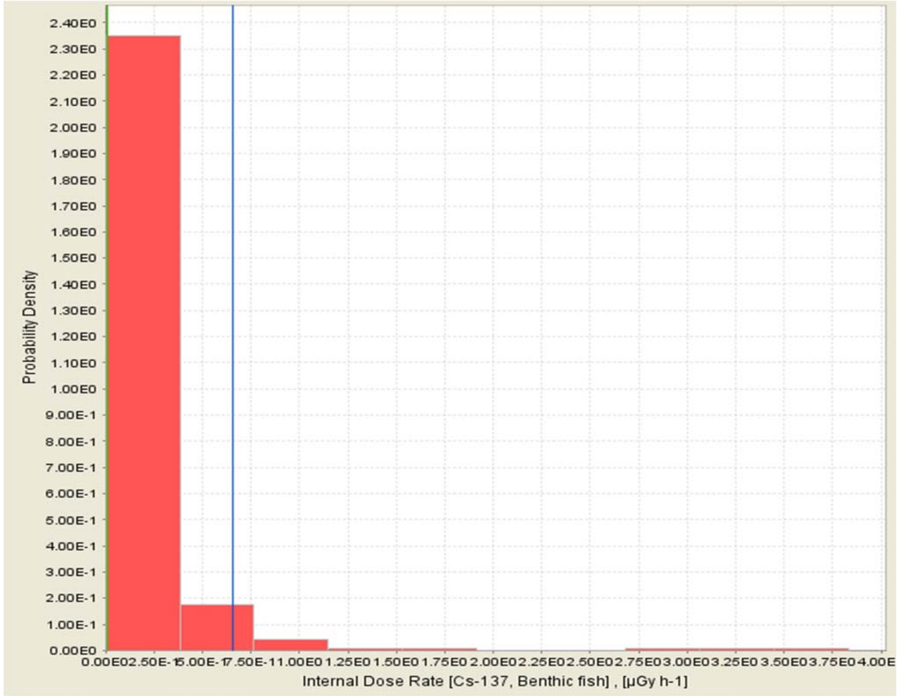


Statistic	**Result**
Mean	3.45E-3
Variance	6.84E-6
5th Percentile	6.83E-4
25th Percentile	1.64E-3
Median	2.97E-3
75th Percentile	4.68E-3
95th Percentile	8.91E-3
Minimum	1.72E-4
Maximum	1.74E-2

Statistic	Result
Mean	2.01E-1
Variance	1.58E-1
5th Percentile	1.13E-2
25th Percentile	4.18E-2
Median	9.46E-2
75th Percentile	1.89E-1
95th Percentile	7.16E-1
Minimum	1.71E-3
Maximum	4.15E0

External, Internal Dose Rates (Benthic fish-summer)

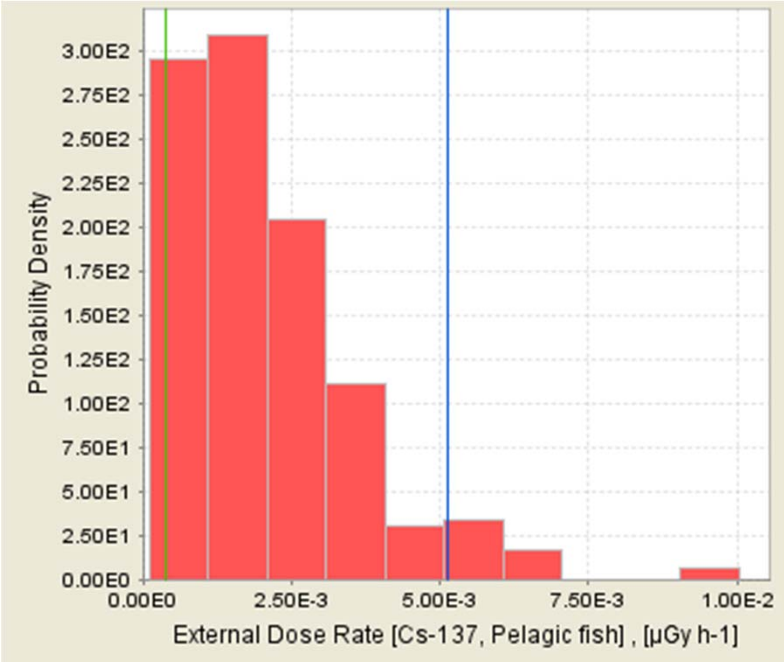


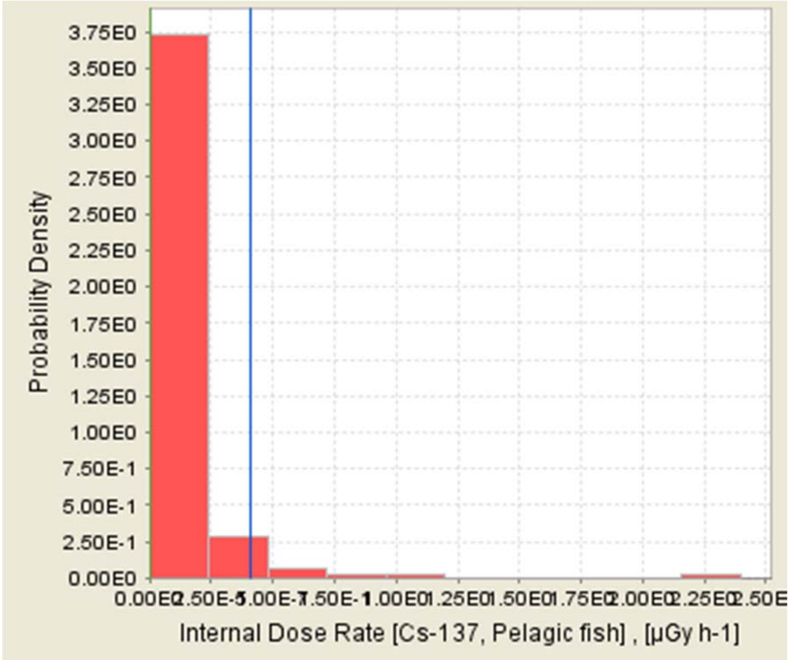


Statistic	Result
Mean	2.77E-3
Variance	4.69E-6
5th Percentile	4.86E-4
25th Percentile	1.14E-3
Median	2.11E-3
75th Percentile	3.64EE-3
95th Percentile	7.33E-3
Minimum	1.48E-4
Maximum	1.23E-2

Statistic	Result
Mean	1.85E-1
Variance	1.41E-1
5th Percentile	7.26E-3
25th Percentile	3.32E-2
Median	7.18E-2
75th Percentile	1.96E-1
95th Percentile	6.57E-1
Minimum	7.03E-4
Maximum	3.8E0

External, Internal Dose Rates (Pelagic fish-winter)

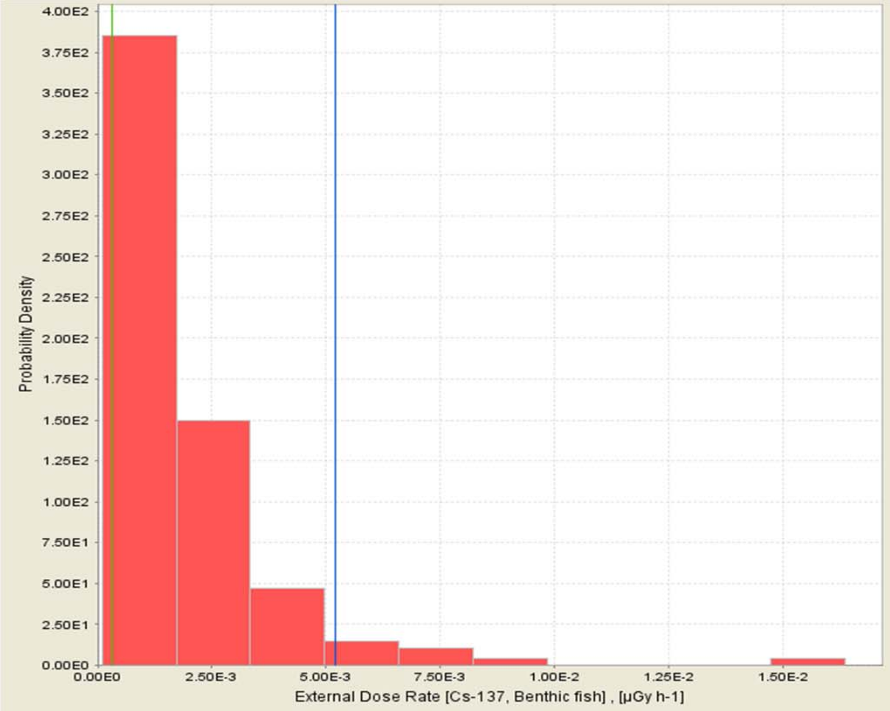


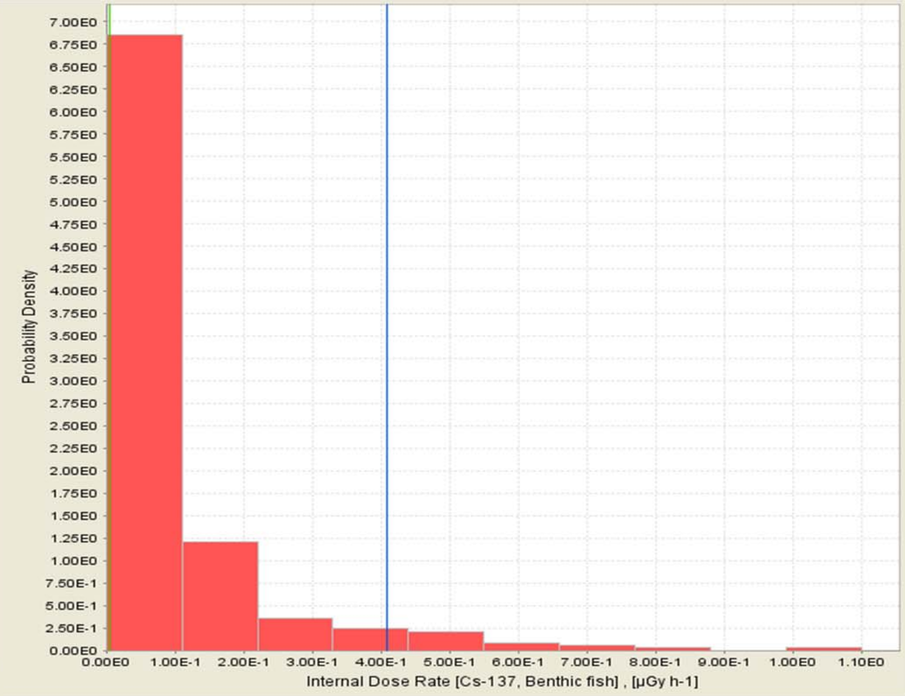


Statistic	Result
Mean	2.04E-3
Variance	2.28E-6
5th Percentile	3.94E-4
25th Percentile	9.44E-4
Median	1.72E-3
75th Percentile	2.70E-3
95th Percentile	5.14E-3
Minimum	9.90E-5
Maximum	1.00E-2

Statistic	Result
Mean	1.16E-1
Variance	5.28E-2
5th Percentile	6.54E-3
25th Percentile	2.42E-2
Median	5.46E-2
75th Percentile	1.09E-1
95th Percentile	4.13E-1
Minimum	9.87E-4
Maximum	2.40E0

External ,Internal Dose Rates (Benthic Fish-winter)





Statistic	Result
Mean	1.84E-3
Variance	3.66E-6
5th Percentile	3.17E-4
25th Percentile	7.35E-4
Median	1.22E-3
75th Percentile	2.33E-3
95th Percentile	5.19E-3
Minimum	9.27E-5
Maximum	1.64E-2

Statistic	Result
Mean	9.97E-2
Variance	2.09E-2
5th Percentile	5.16E-3
25th Percentile	1.91E-2
Median	4.91E-2
75th Percentile	1.09E-1
95th Percentile	4.09E-1
Minimum	6.16E-4
Maximum	1.10E0

Internal dose rates (human consumption of fish)

CALCULATION FORMULA

$$D = 0.5 \cdot \sum_{j=1}^{m} DCF_j \cdot CF_j \sum_{i=1}^{n} A_i \int_0^T C_{ij}(t)\,dt ,$$

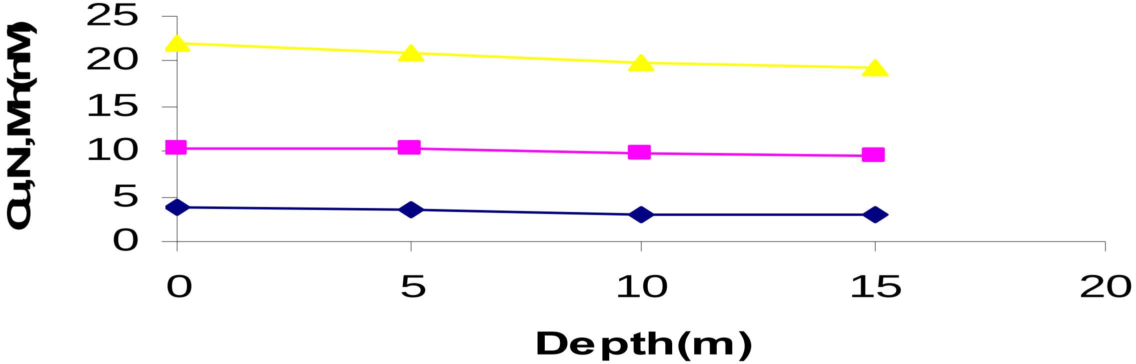
where [0, T] is the time interval (y); DCFj (Sv/Bq) is the dose conversion factor for radionuclide *j* (j = 1,2,..., m); CFj (m3/t) is the concentration factor for radionuclide *j* in fish; Ai (t/y) is catch of fish in the model compartment *i*; (*i* = 1,2,...,n); Cij (Bq/m3) is the concentration of radionuclide *j* in filtered seawater in model compartment *i*; and 0.5 is the edible fraction for fish.

Pelagic fish

(Winter) D = 0.010mSv

(Summer) D = 0.017mSv

The model vertical profiles of Cu, Ni, Mn



Cu, Ni, Mn (blue, red, yellow line, respectively) concentrations versus depth

Heavy metals concentrations

Calculation formula

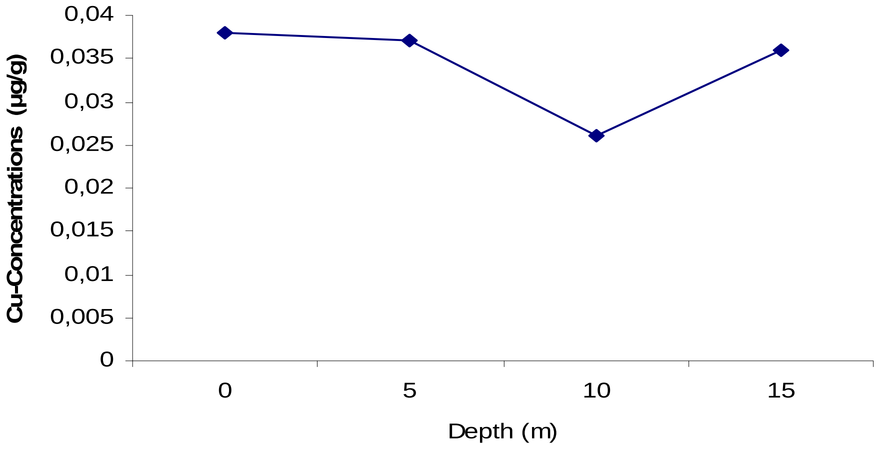
$$C_f = C_{tc} / C_e$$

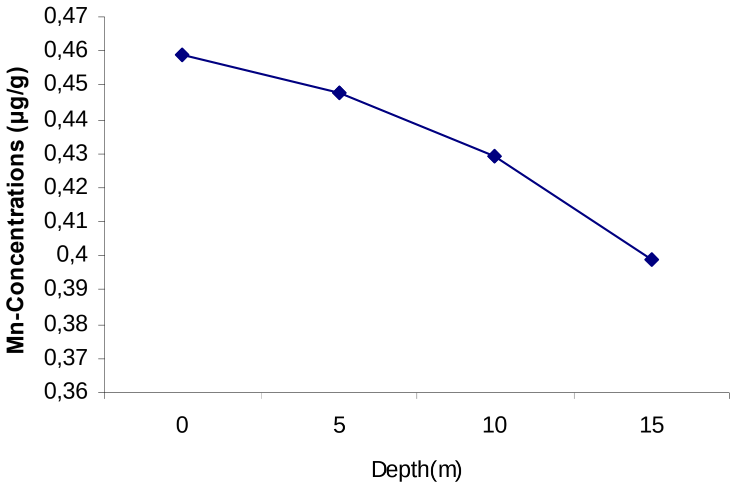
C_f, concentration factor

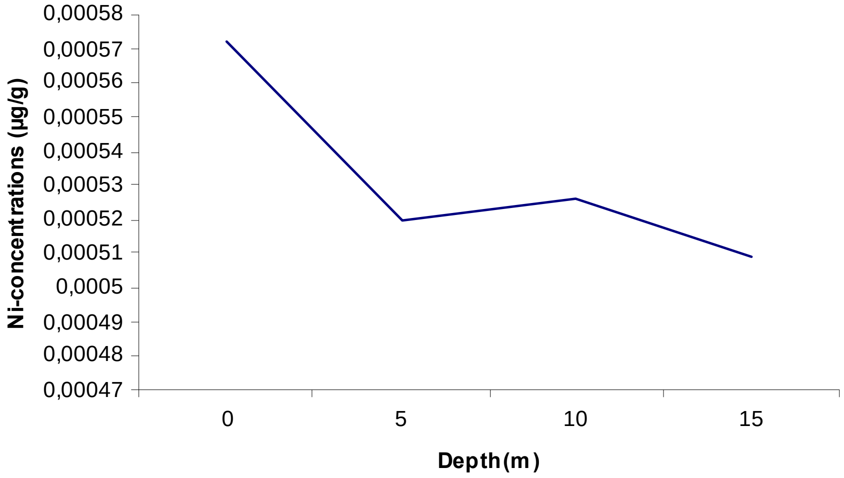
C_{tc}, metal concentration in a trophic component

C_e, metal concentration of abiotic environment

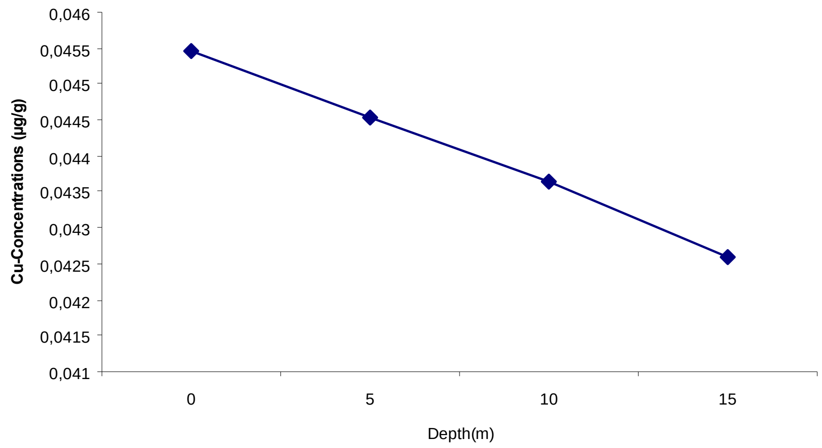
Heavy metals concentrations-Pelagic Fish

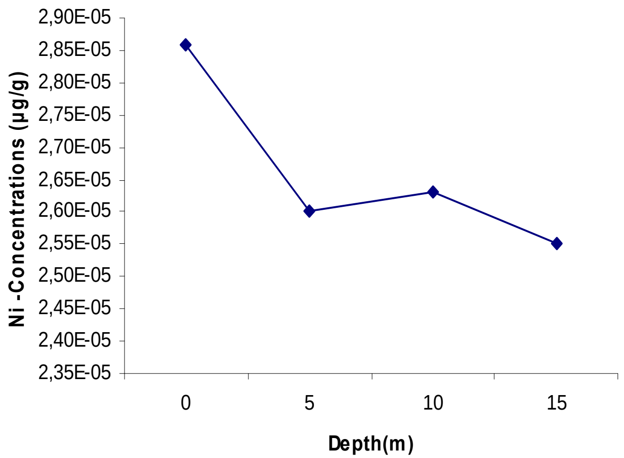


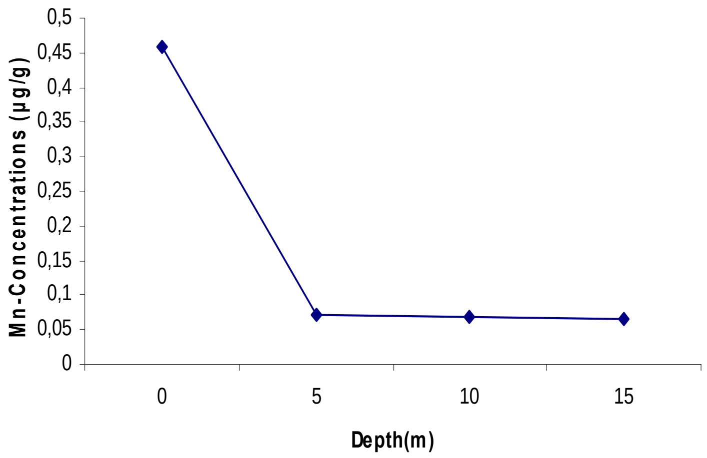




Heavy metals concentrations-Human







Conclusions

•The model values of the 137Cs activity concentrations are in accordance with the measured values. The combined methodology of model and dose rate formula results to the prediction of the radiological impact. Besides, the model values for the heavy metals are in accordance with the used published data.

•The model has general structure -can accommodate any other processes deemed necessary.

•It is feasible to estimate the ecological and environmental risk.

Future research

Modeling the effects of radioactivity in molecular level

We wish to thank Dr Heleny Florou (NCSR"Demokritos" INT-RP/ERL) and her colleague Dr.Georgia Trabidou for providing us experimental data on 137Cs and species data. Also, we wish to thank Mr Mikhail Iosjpe (Norwegian Radiation Protection Authority) for providing us the calculation formula for the internal dose rates estimations to human due to consumption of fish.

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