External radiation doses to biota Monte Carlo dose model calculations with TADPOLE



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Background

- In radiological environmental protection, realistic dose models are needed in site-specific risk assessments for biota
- Little guidance exists for cases where the screening values are exceeded
- Screening dose models do not calculate doses from heterogeneous distributions of radionuclides in the soil profile
- It can be important to be able to calculate doses to organs such as skin, liver, and gonads in reference organisms



The aim of the project

- To develop Monte Carlo models applicable to detailed external dose calculations of non-human biota in the vicinity of a radioactive medium
- To develop a dose model that can calculate external dose rates to specific organs in biota from a soil profile with heterogeniously distributed radionuclides, taking the soil characteristics into account
- To verify the dose models in experiments with frog- and worm phantoms



Methods

- Monte Carlo N-Particle Transport Code version 5 (MCNP5)
- Graphical user interface TADPOLE, Terrestrial and Aquatic Dose assessment Program for Organisms in their Local Environment
- Only a few parameters are fixed to make it applicable to a wide range of exposure situations
- Created a user manual for TADPOLE

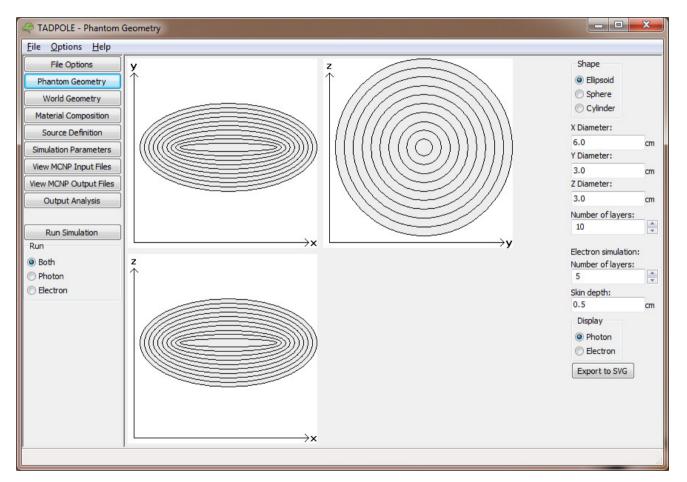


TADPOLE

- The radioactive medium has the shape of a cylinder
- The organism can be placed at any depth
- The size and shape of the organism can be defined
- The size of the surrounding material volumes can be defined
- The depth distribution of elemental compositions and activity concentrations can be defined
- Determines the absorbed dose per day to the organism as a function of depth



TADPOLE: phantom geometry menu

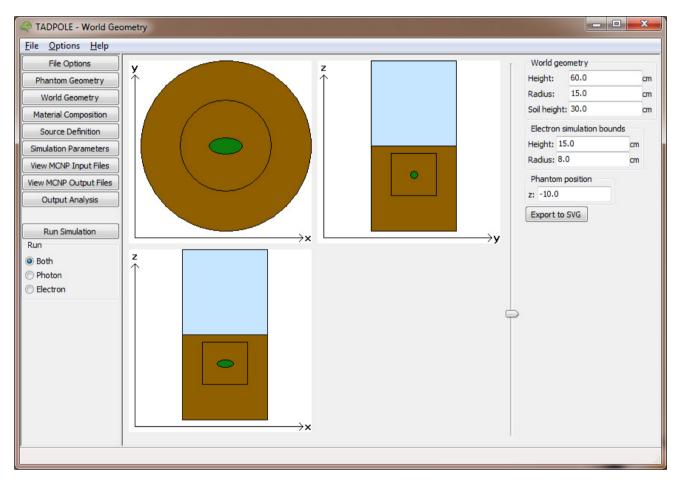


Size and shape of the organism



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TADPOLE: world geometry menu



The size of surrounding and upper medium, and position of the organism



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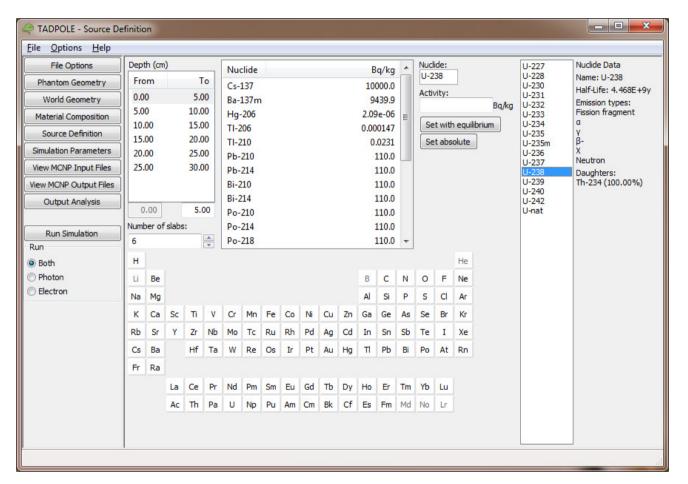
TADPOLE: material composition menu

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University

TADPOLE: source definition menu





TADPOLE: output analysis menu

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View MCNP Input Files	0.04 - 0.06	3.55741e-06	4.07323e-07	2, 10	4:		
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	0.10-0.12	1.05422e-06	2.60076e-07	2, 10	8:		5
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	0.15-0.17	4.95049e-07	1.63614e-07	2, 5, 10		0: PDF slope	
Run	0.17-0.19	4.37225e-07	1.82541e-07	2, 5, 10		ose rate (µGy/day)	
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) Photon	0.21-0.23	1.45775e-07	6.77852e-08	2, 5, 8, 10			
Electron	0.23 - 0.25	6.73205e-08	3.73292e-08	2, 5, 10			
	0.25 - 0.27	8.01193e-08	4.68057e-08	2, 5, 10			
	0.27 - 0.29	6.7366e-08	3.81629e-08	2, 5, 8, 10			
	0.29 - 0.31	1.77968e-07	1.41609e-07	2, 5, 7, 10		h	
	0.31 - 0.33	1.31523e-07	9.25662e-08	2, 5, 10			
	0.33 - 0.35	9.43111e-08	6.16794e-08	2, 5, 10			
	0.35 - 0.37	1.07746e-07	6.20295e-08	2, 5, 10		1	
	0.37 - 0.38	1.45797e-07	8.48246e-08	2, 5, 7, 10		k	
	0.38 - 0.40	1.61007e-07	8.85537e-08	2, 5, 10		15	
	0.40 - 0.42	1.50273e-07	8.46938e-08	2, 5, 7, 10		1	
	0.42 - 0.44	1.55702e-07	9.05562e-08	2, 5, 7, 10	-0	0.01 0.00	3.0
	0.44 - 0.46	2.1562e-07	1.39873e-07	2, 5, 10 👻		Depth (cm)	5.0



Verification experiment 1: laboratory measurement

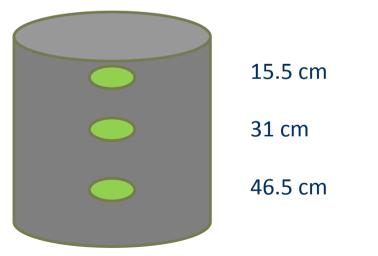
- To verify calculations with TADPOLE
- Frog-phantoms of PMMA with TLDs were prepared



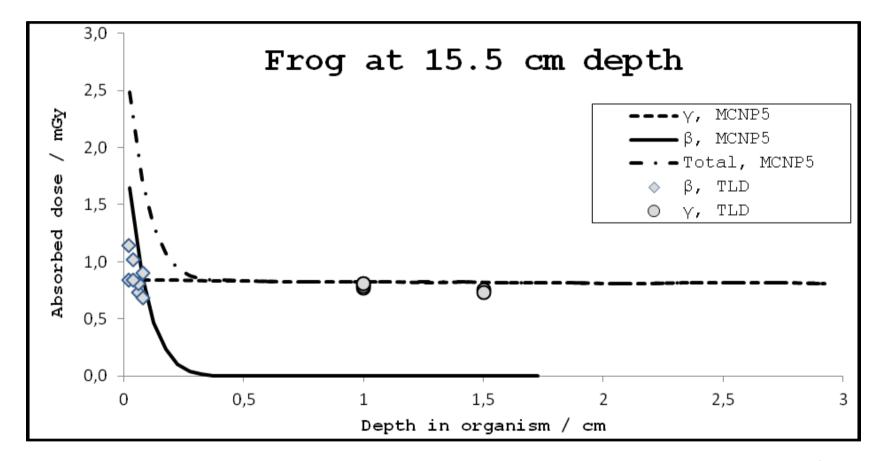


Verification experiment 1

- The frog-phantoms were positioned at three different depths in a homogeneous medium of KNO₃ in a steel barrel with a radius of 28.35 cm, 62 cm high
- 12 dosimeters placed at different depths
- Activity conc. of 40 K in medium was 12 100 ± 350 Bq/kg.
- The exposure lasted 50 days.









Verification experiment 2: field measurement

- The study site was a wetland area in Utnora, Sweden, that have receive fallout of ¹³⁷Cs from the Chernobyl accident in 1986.
- Four frog-phantoms and two worm-phantoms of PMMA with TLDs were prepared.



 The frog-phantoms were placed at 3, 5, 10 and 15 cm depth and the worm-phantoms were placed at 5 and 10 cm depth.

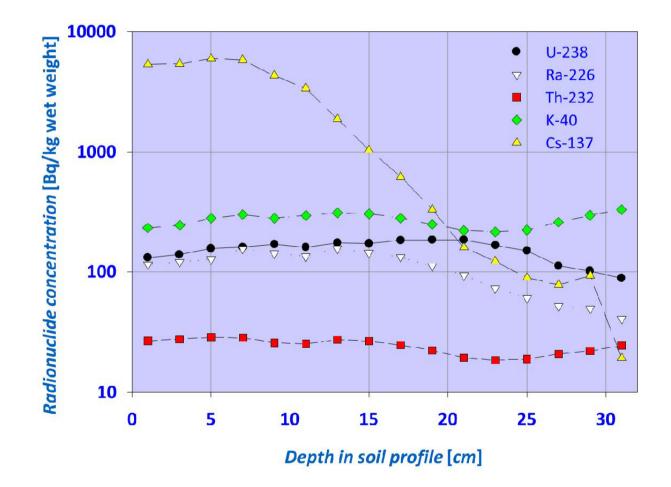


Verification experiment 2: field measurement

- Four soil cores of 10 cm diameter were collected, 1 meter in different directions from phantom positions. Sliced in 2 cm segments down to 30 cm.
- Activity concentrations of main radionuclides ¹³⁷Cs, ⁴⁰K, ²³⁸U, ²²⁶Ra, ²³²Th were analyzed at Linköping University.
- Material composition of soil were analyzed in the profile by ICP-MS and GC techniques by ALS Scandinavia AB.
- Exposure lasted 200 days over the winter period.

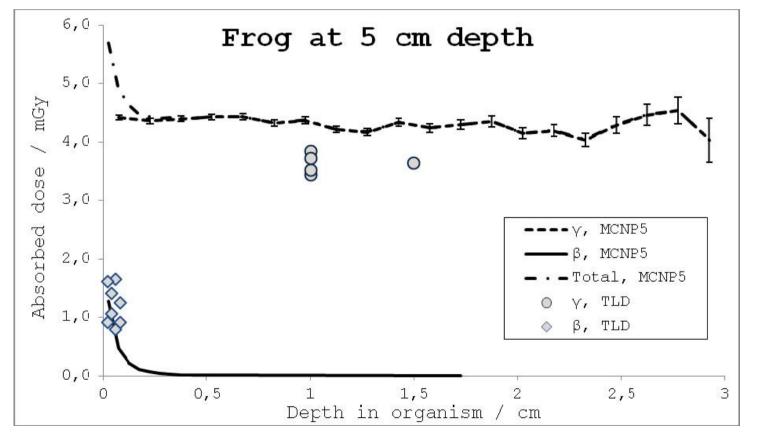


Verification experiment 2: field measurement



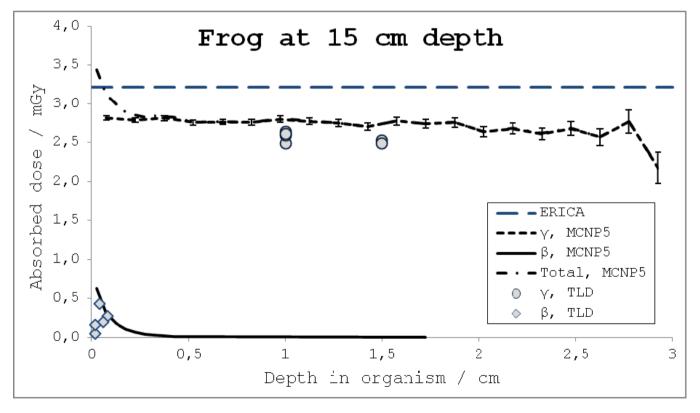


• In TADPOLE the soil cylinder were set to assure at least 75 cm of soil laterally and below the organism.



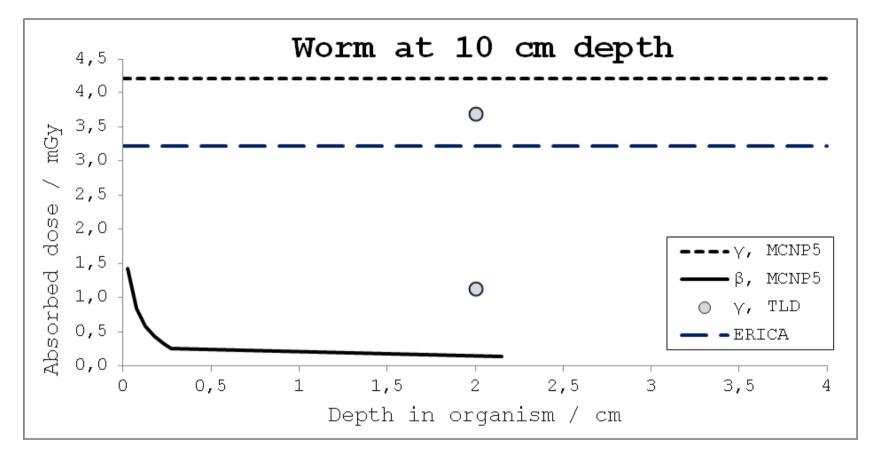


• Calculations with ERICA tool were performed for a frog and a worm positioned at 25 cm depth in 50 cm thick soil. The activity was set to mean of upper 10 cm.





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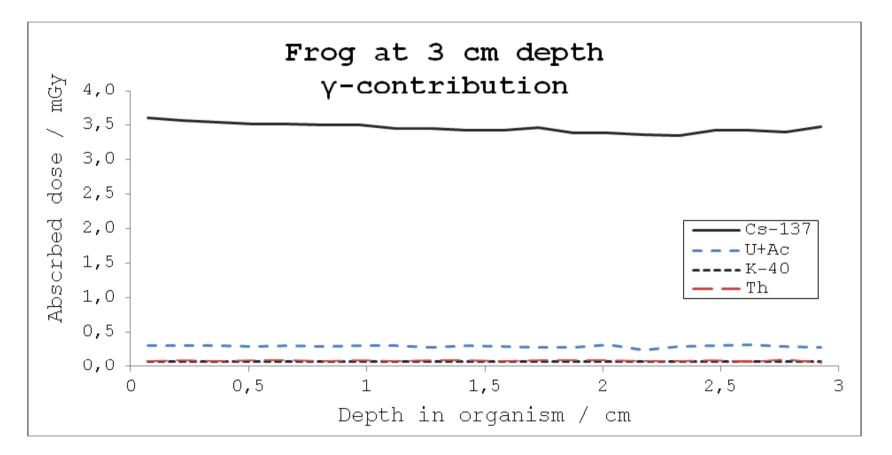




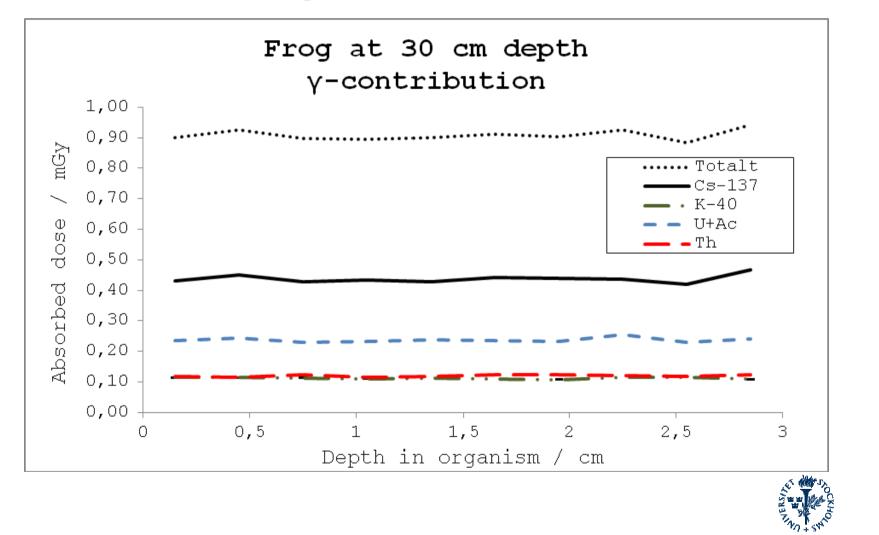
Verification experiment 2: Factors affecting results

- The exposure was performed during the winter period and the sampled soil may not have been characteristic for the whole period, especially concerning water content.
- Secular equilibrium was assumed between ²²⁶Ra and ²²²Rn and its daughters which may overestimate the source term.
- The TLD response may have been affected by the cold conditions.
- The magnitude of post-irradiation fading of the TLD in situ may differ from literature data, obtained in controlled laboratory conditions.









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Conclusions

- A graphical editor TADPOLE was created to facilitate dose calculations with MCNP5. It is designed for site-specific assessment of external doses to wildlife.
- A first verification experiment in the lab resulted in TLD doses to frog-phantoms close to calculated doses.
- A second verification experiment in the field resulted in frogand worm-phantom measurements significantly different from calculated doses possibly due to insufficient control of environmental parameters during the winter period.
- TADPOLE can be a useful dose model when detailed, sitespecific dose assessments are needed (soil profiles, sensitive organs) and has the potential to be extended to also cover internal dose calculations in the future.

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Thank you for your attention!

