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Ten years of monitoring ^{14}C activity in atmospheric CO_2 and biological samples around the Nuclear Power Plant Krško, Slovenia

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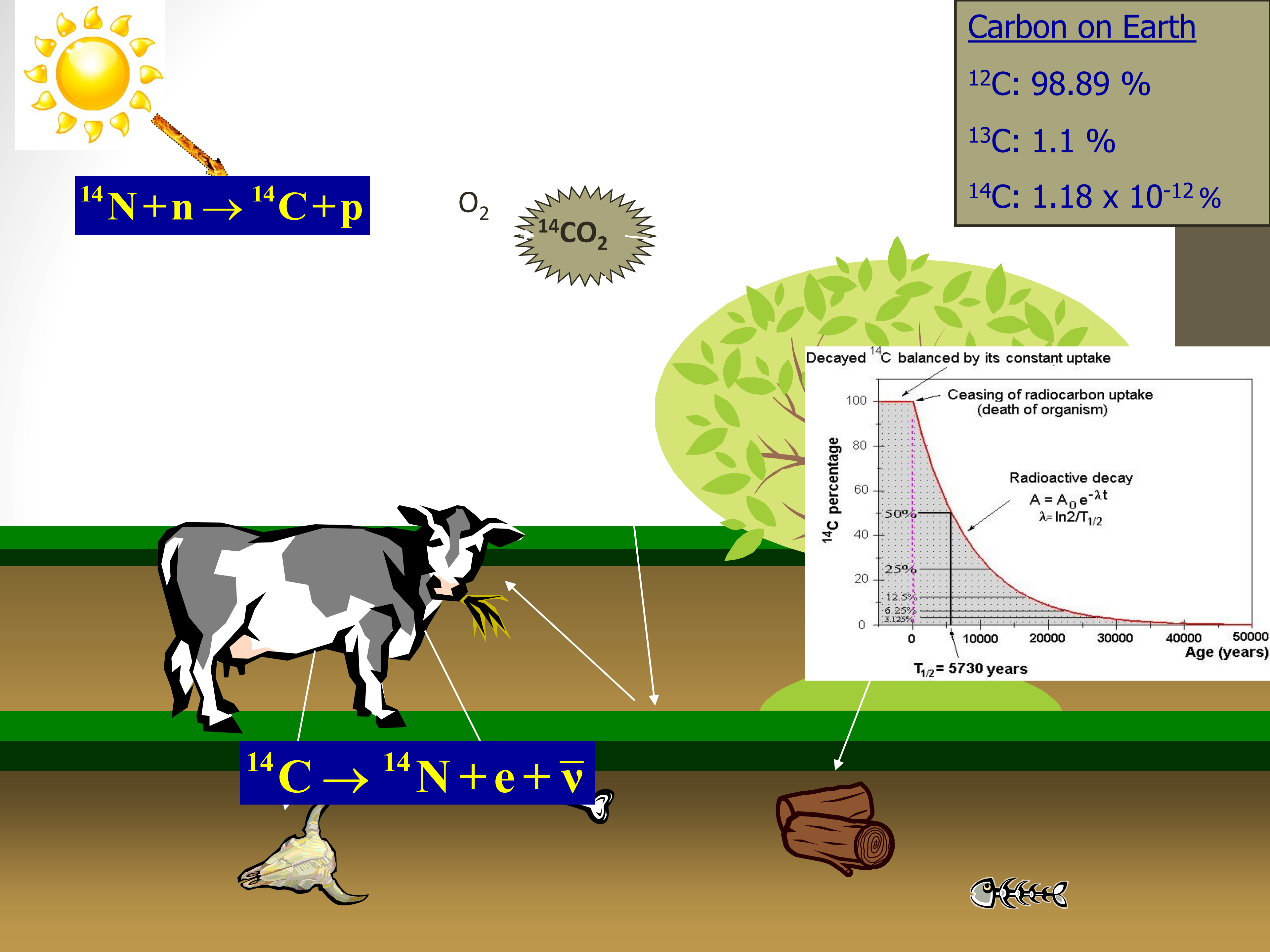
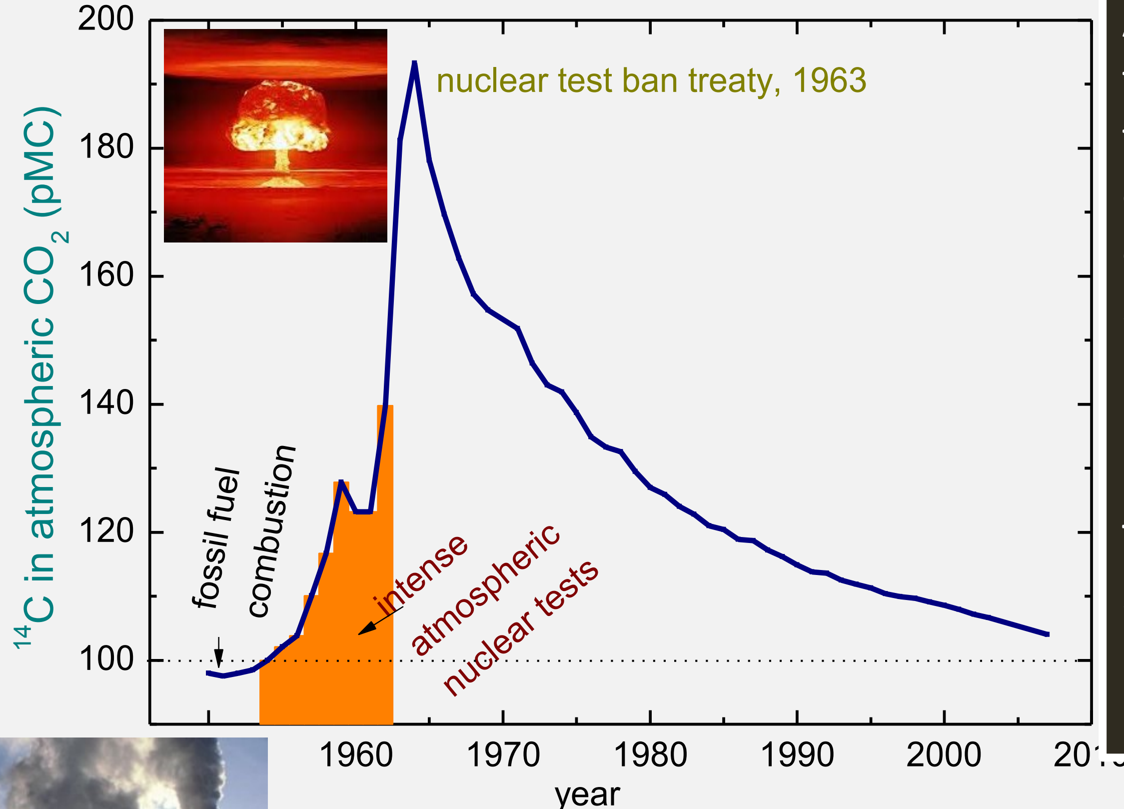


Carbon on Earth
^{12}C: 98.89 %
^{13}C: 1.1 %
^{14}C: 1.18 x 10^{-12} %
$^{14}N + n \rightarrow {}^{14}C + p$
O_2
$^{14}CO_2$
Decayed ^{14}C balanced by its constant uptake
Ceasing of radiocarbon uptake (death of organism)
Radioactive decay
$A = A_0 e^{-\lambda t}$
$\lambda = \ln 2 / T_{1/2}$
^{14}C percentage
100
80
60
50%
40
25%
20
12.5%
6.25%
3.125%
0
0
10000
20000
30000
40000
50000
Age (years)
$T_{1/2}$ = 5730 years
$^{14}C \rightarrow {}^{14}N + e + \overline{\nu}$

Anthropogenic ^{14}C



Anthropogenic activities disturbed the natural distribution of ^{14}C in the atmosphere through fossil fuel combustion (increasing of ^{12}C compared to ^{14}C)
and atmospheric bomb tests (doubling the natural atmospheric ^{14}C activity in 1960-ties).

The „bomb-peak” has served as an invaluable tracer to get insight into the global carbon cycle on the decadal time scale.

^{14}C in nuclear power plants

Carbon-14 can be produced in:

- $^{13}C(n,gamma)^{14}C$ and $^{17}O(n,alpha)^{14}C$ with thermal neutrons
- $^{15}N(n,d)^{14}C$ and $^{16}O(n,^{3}He)^{14}C$ with fast neutrons

In PWR ^{14}C is produced by neutron activation with oxygen ^{17}O or nitrogen ^{14}N in fuel, moderator and coolant of the reactor. It is emitted into the environment in the form of **CO_2**, which **enters the natural carbon cycle** in the vicinity of power stations. Through food chain (ingestion) it can contribute to the additional irradiation of the population, resulting thus to the enhancement of the effective dose of the population.

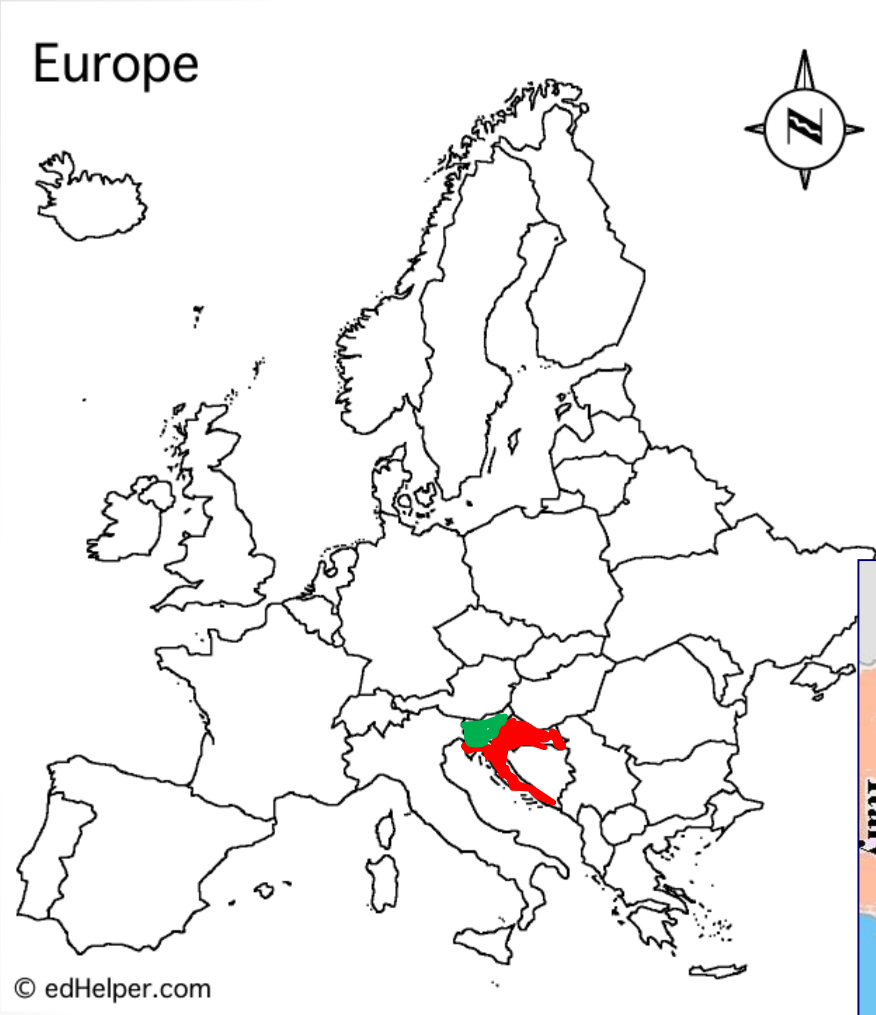
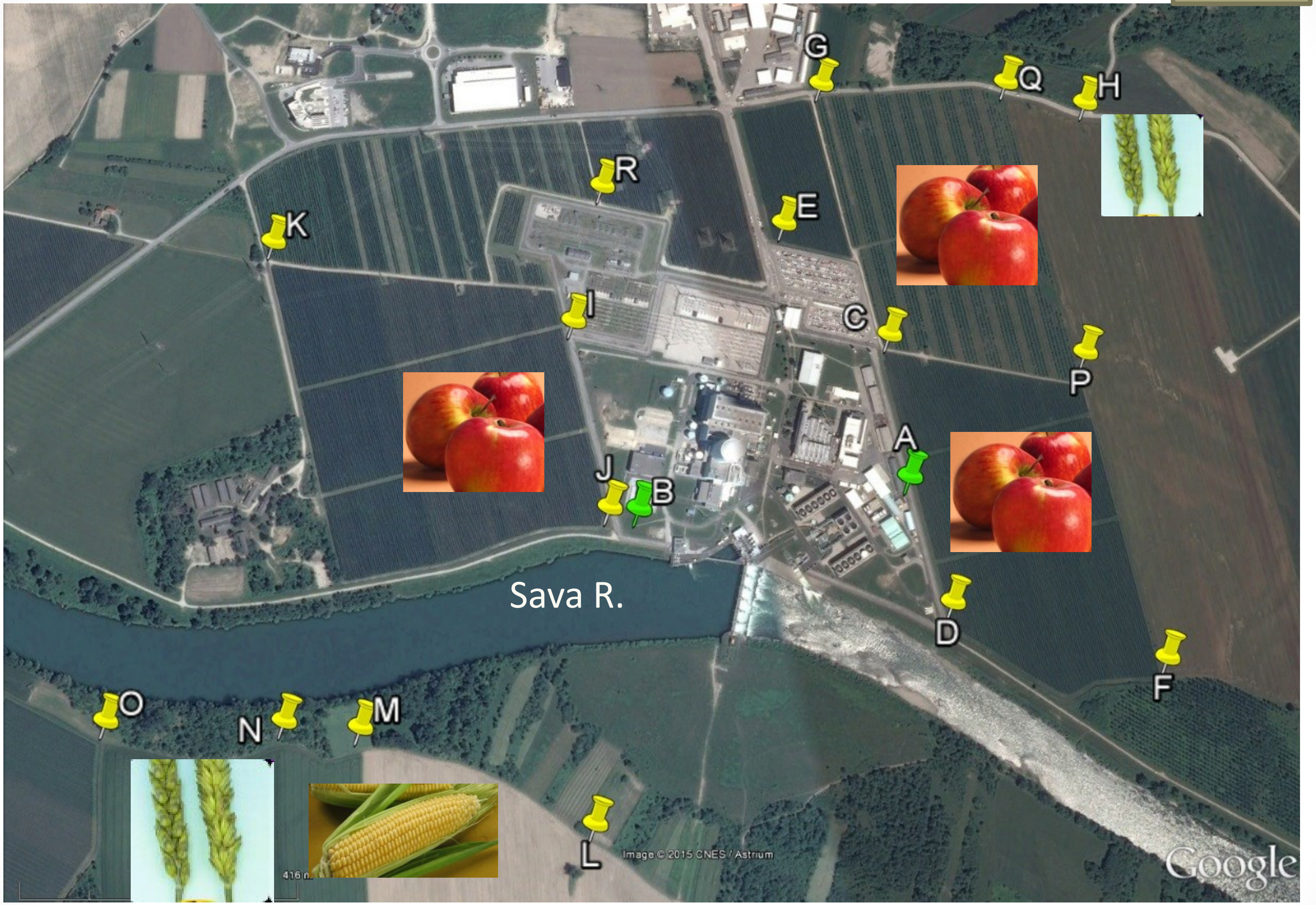
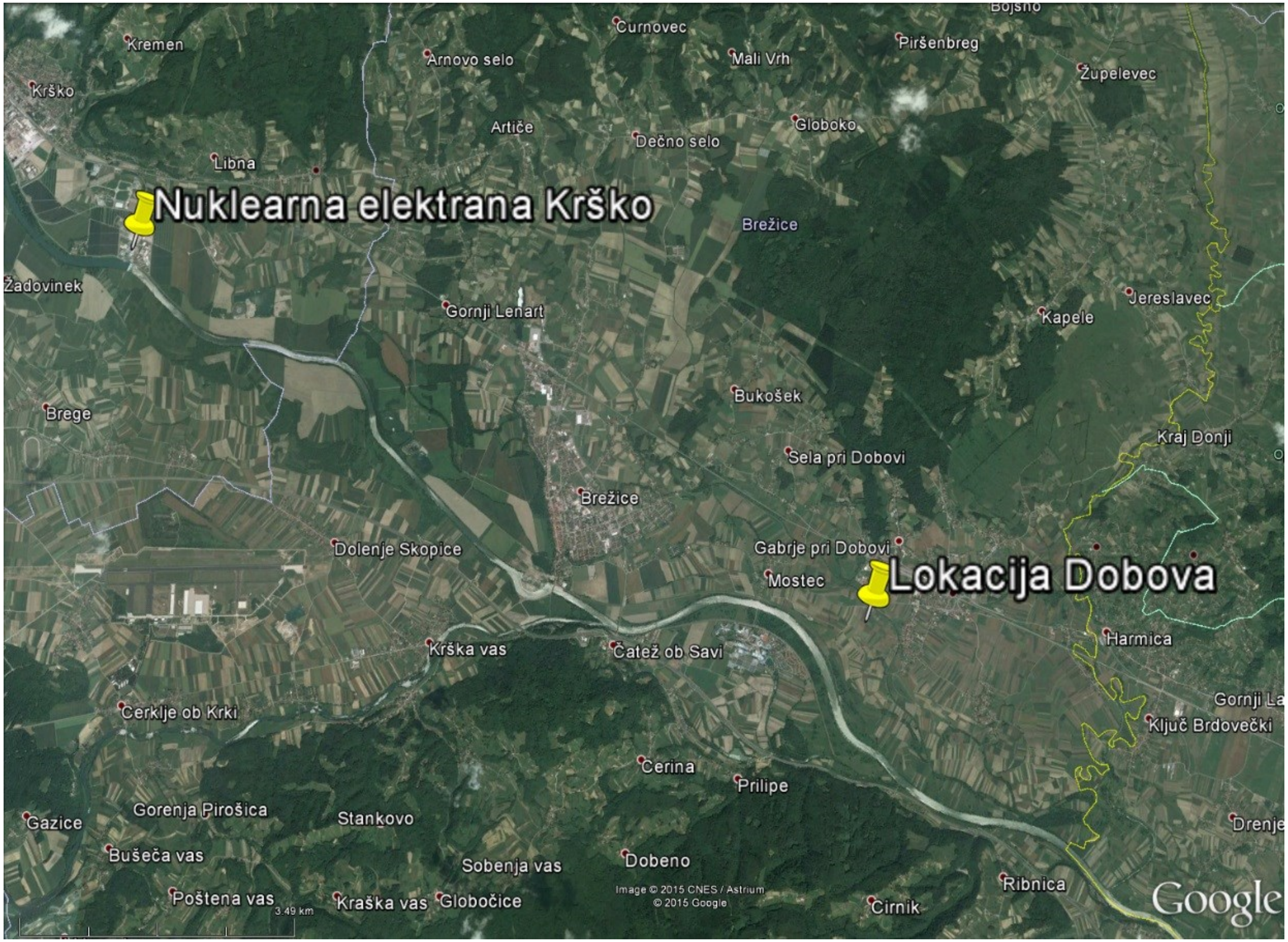


Figure 1. Sampling sites Krško and Dobova.

NEK



NEK



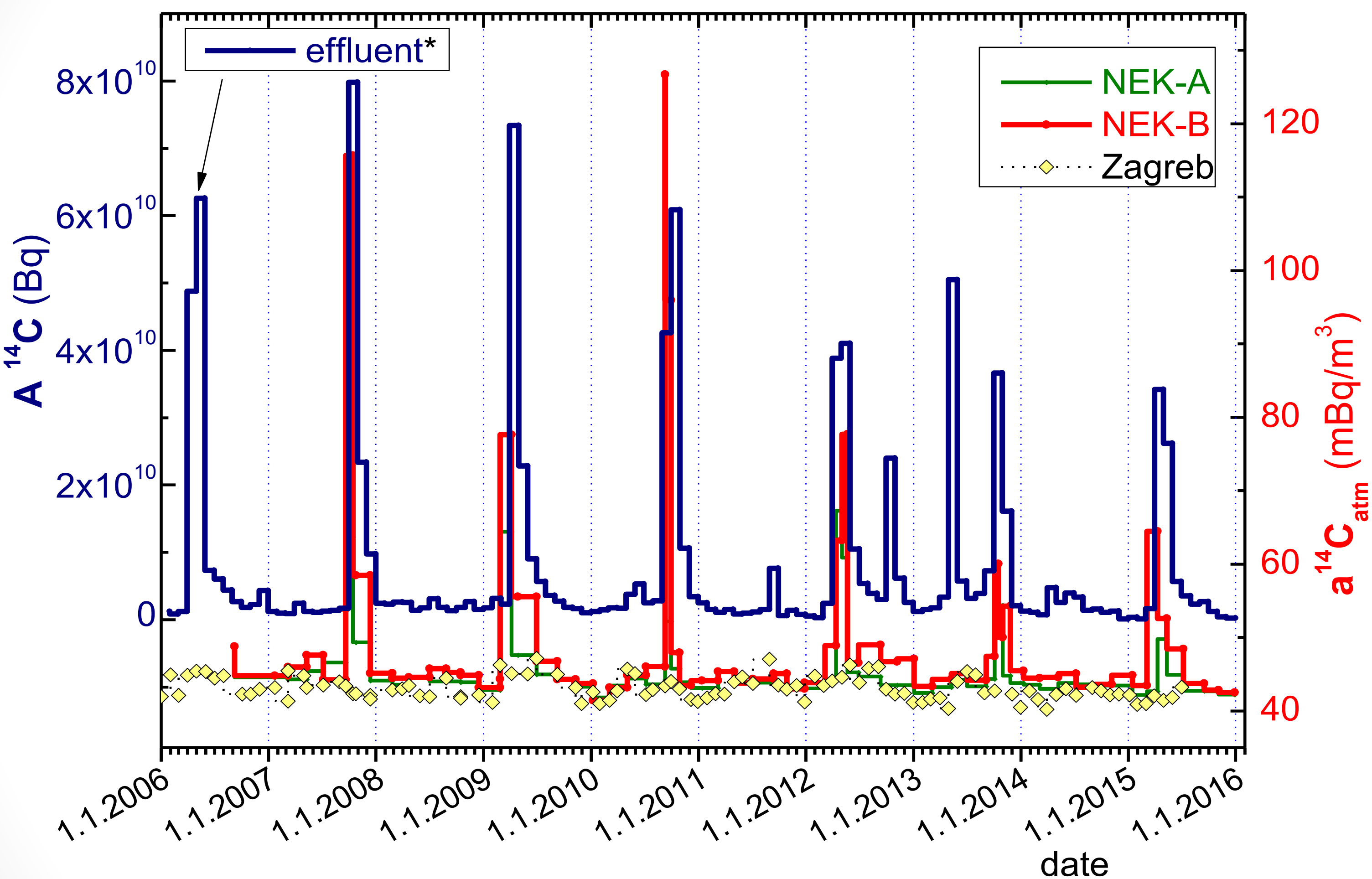
Control site Dobova, not influenced by NEK

Atmospheric CO_2

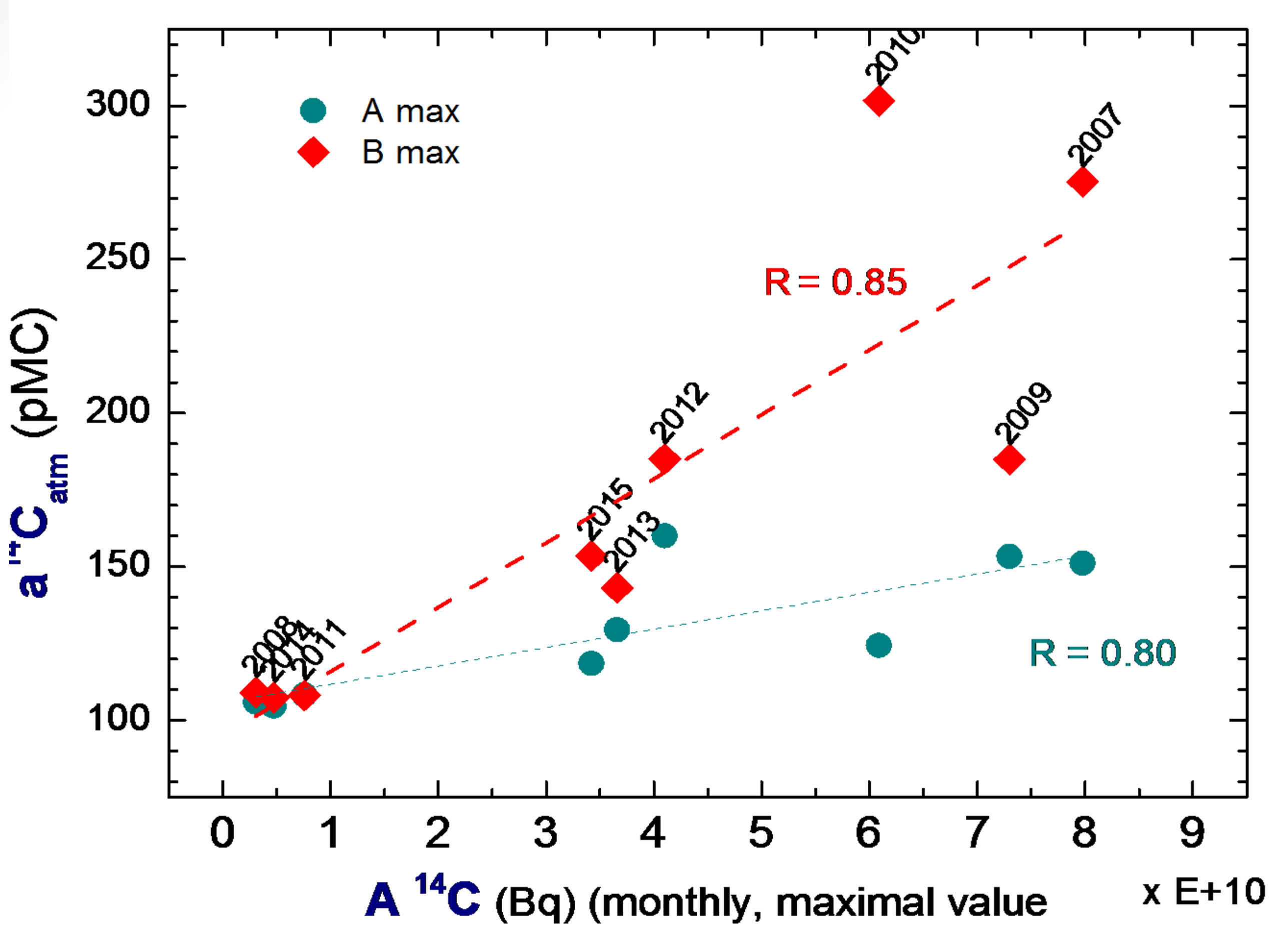
Tray with saturated NaOH
(location **B**)

- **Absorption of atmospheric CO_2 on saturated NaOH during 2-month periods forming Na_2CO_3** (shorter period exceptionally during the refueling process)**;**
- **Na_2CO_3 reacts with HCl and obtained CO_2 is transformed to benzene;**
- **Measurement of ^{14}C activity in liquid scintillation counter (LSC) *Quantulus 1220.***

Atmospheric CO_2



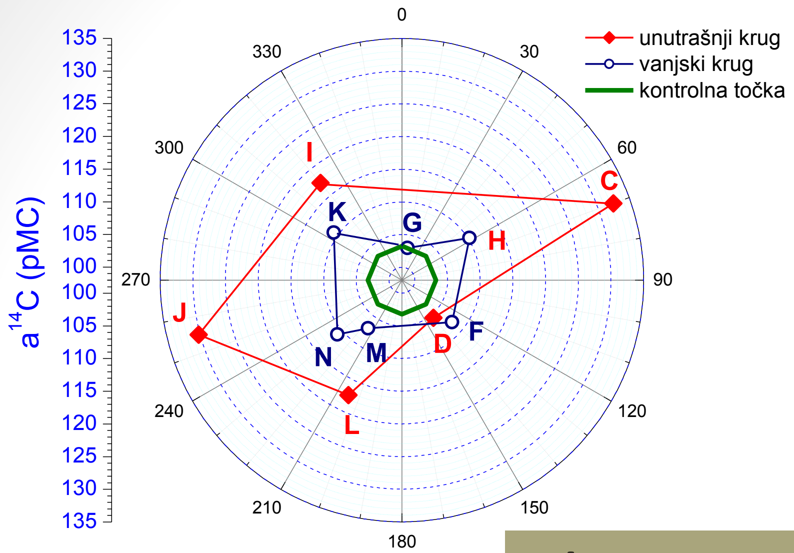
* measured at J. Stefan Inst., Ljubljana, Slovenia

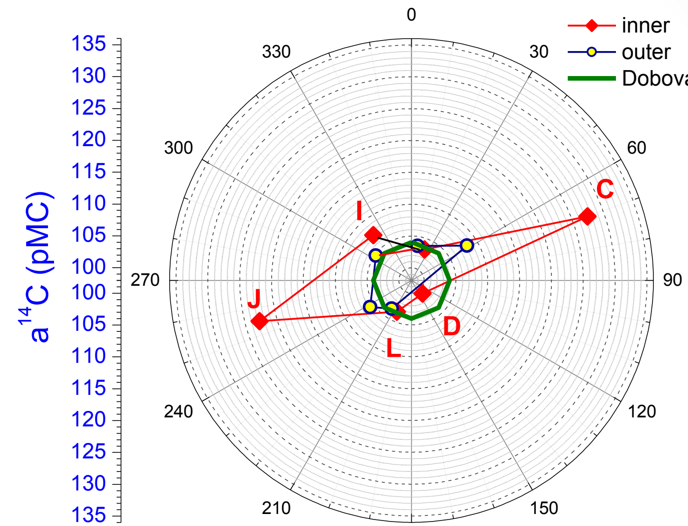


^{14}C activity in atmospheric CO_2 at locations **A** and **B** (maximal values), correlated with the highest ^{14}C activity in monthly gaseous effluents released during the outage periods. Atmospheric ^{14}C activity at the location **B** is always slightly higher than that at the location **A**.

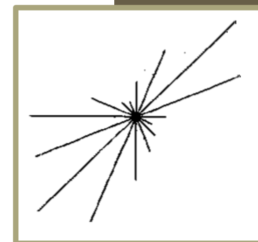
The higher the ^{14}C activity of gaseous effluent, the higher the atmospheric ^{14}C activity.

^{14}C in biological samples, spatial distribution

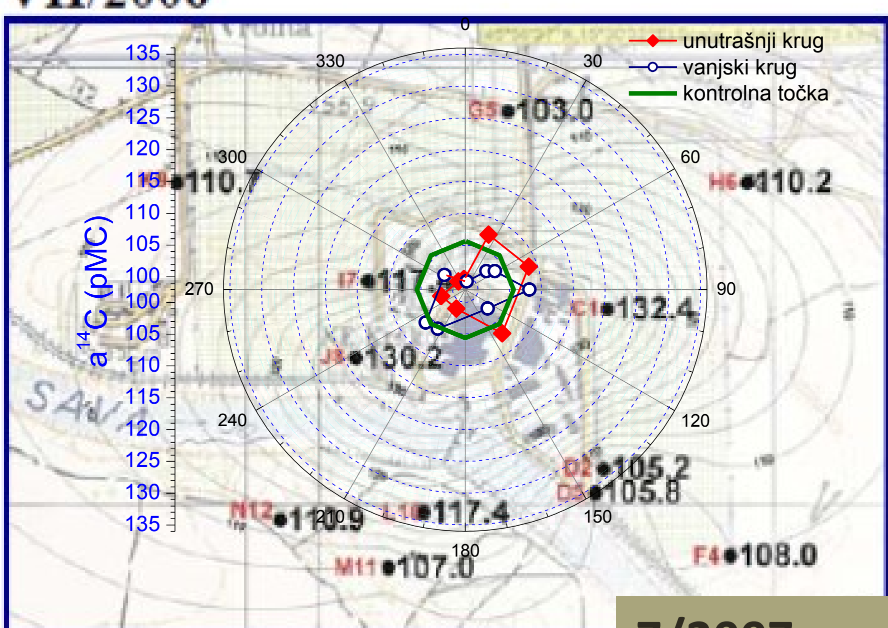


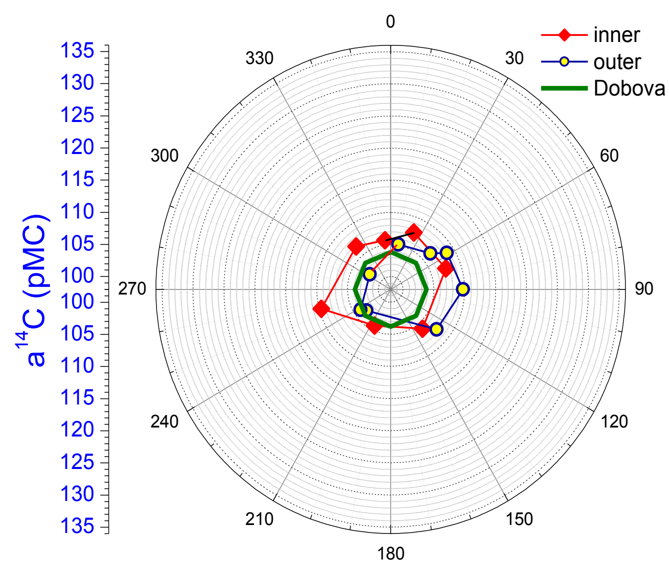


7/2006 refueling **10/2006**



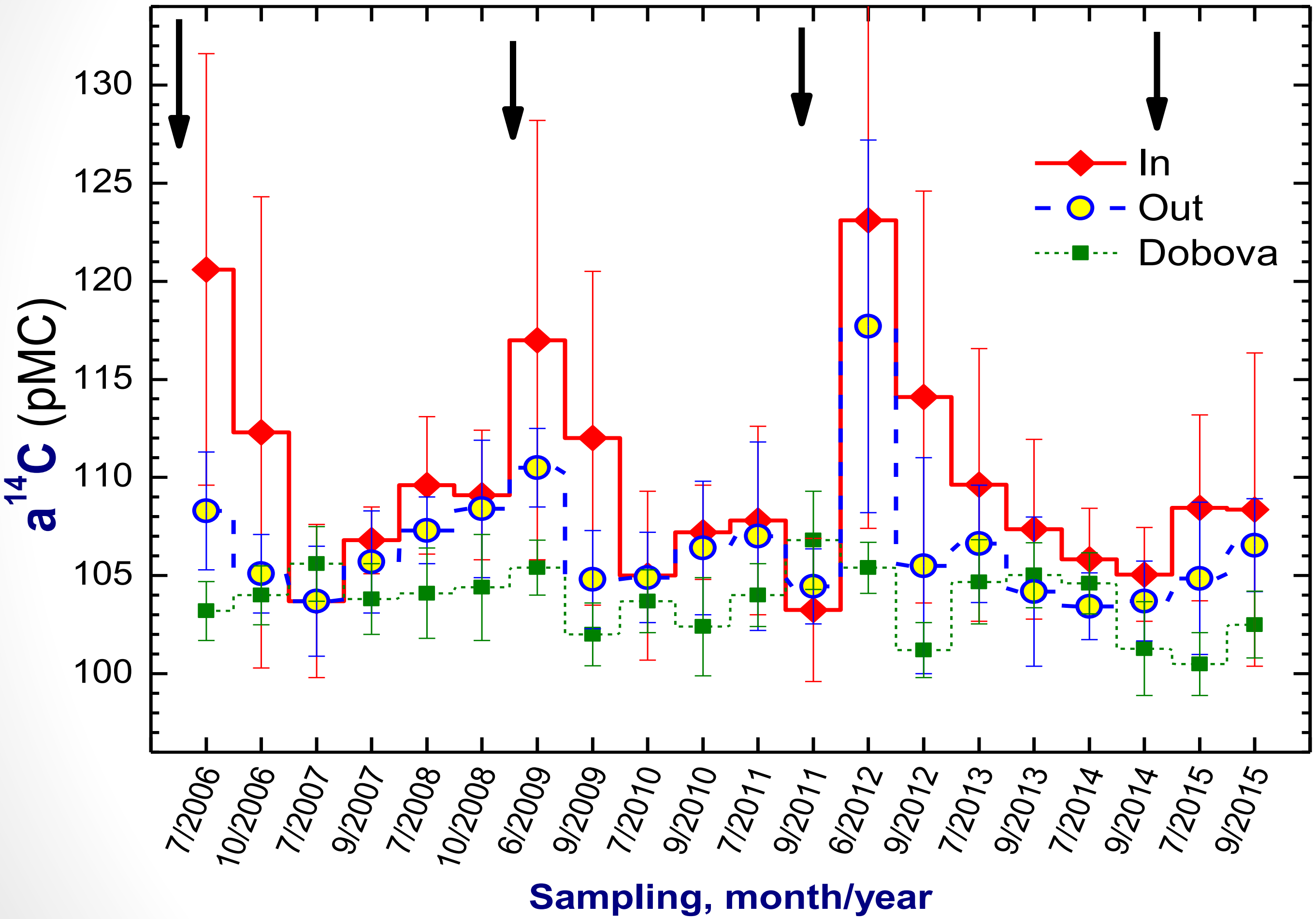
VII/2006

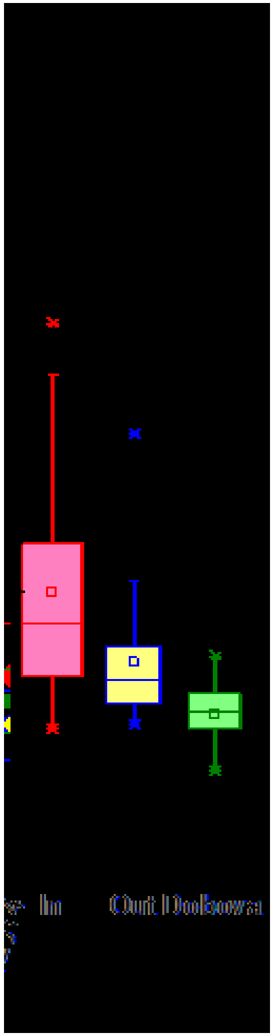


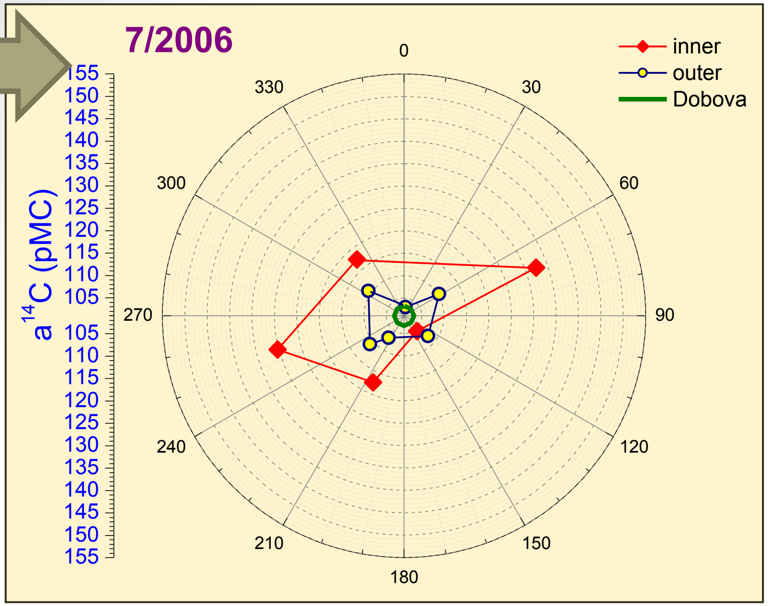


7/2007 **9/2007**

Seasonal average values







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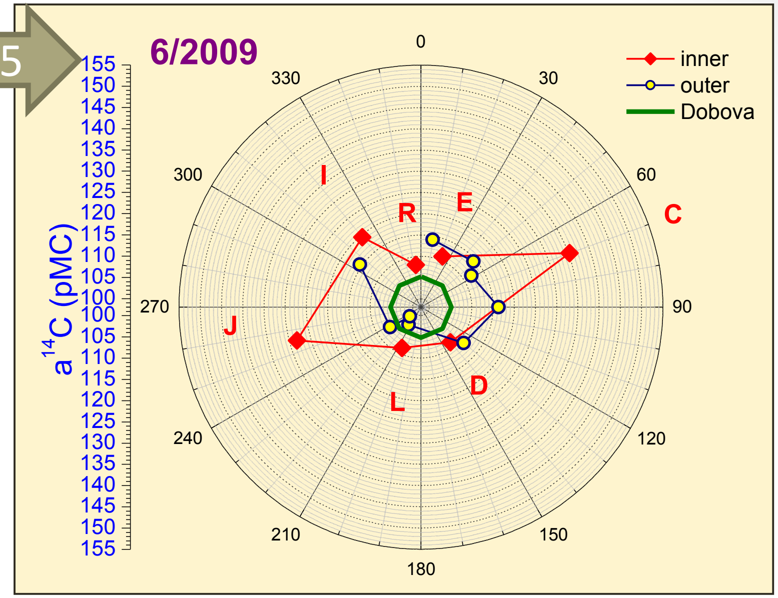
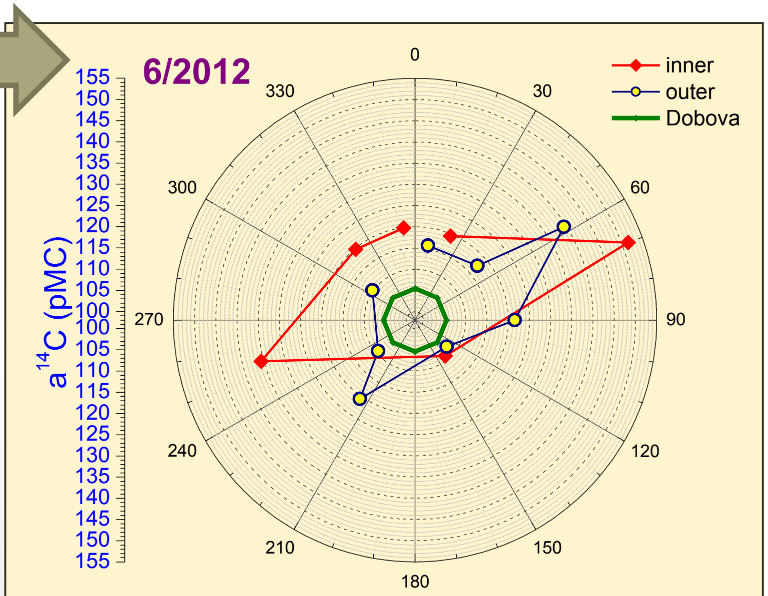
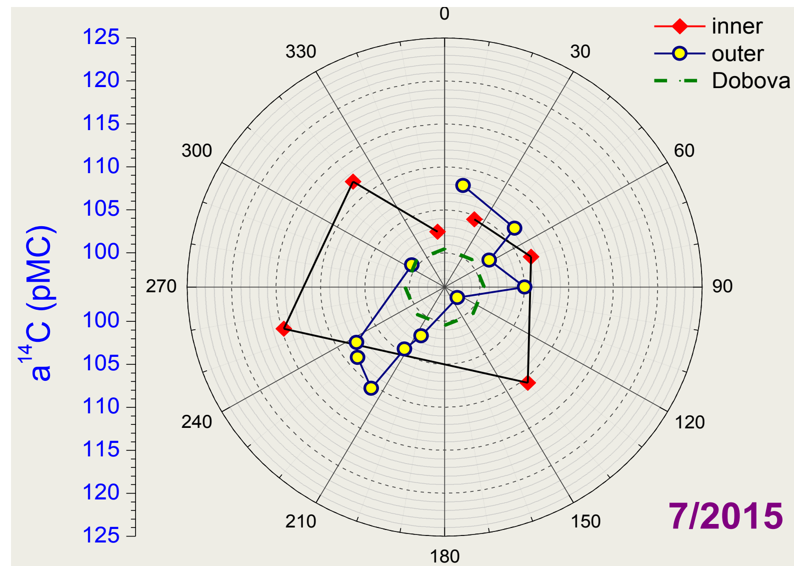
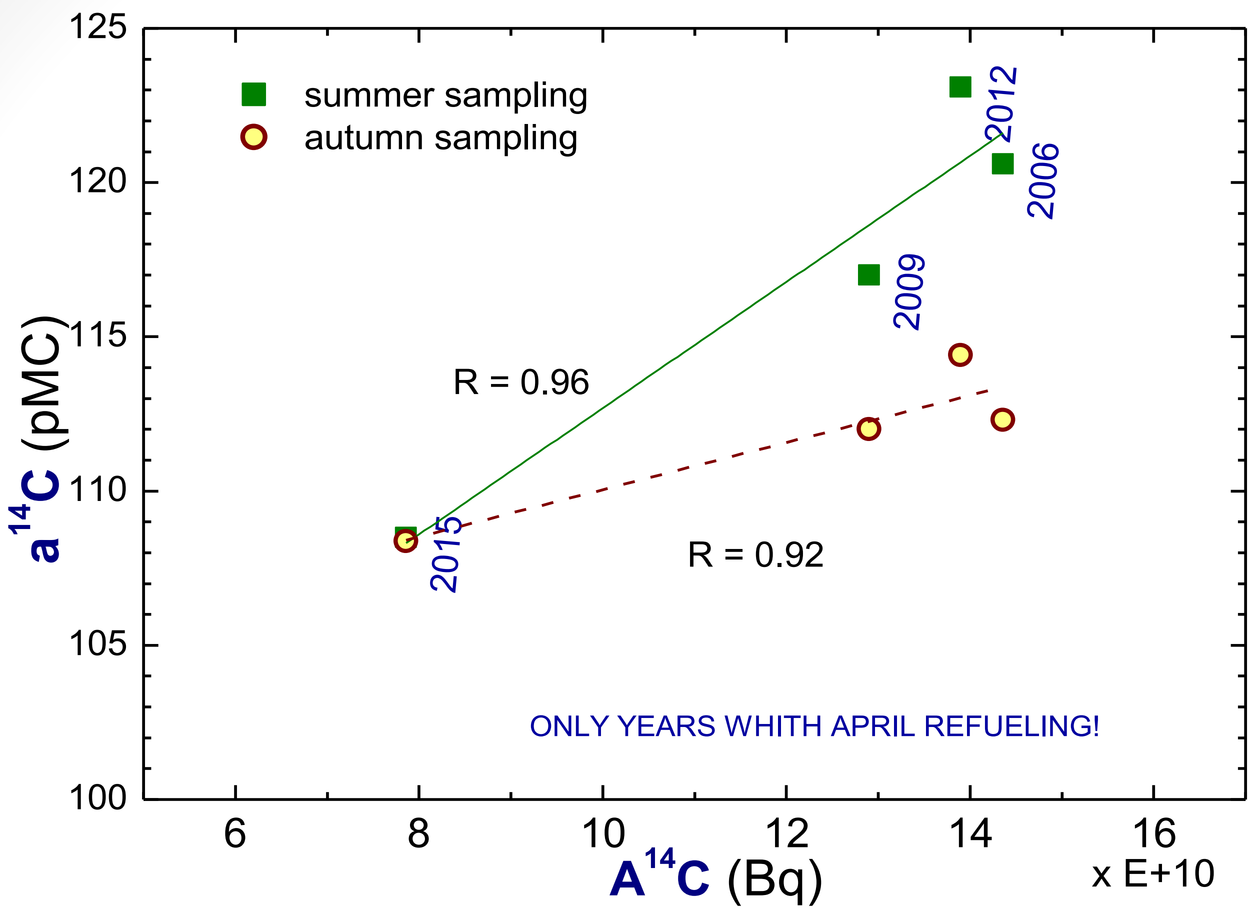






Summer sampling, after refueling in April



Dependence of the mean ^{14}C activity ($a^{14}C$) of samples from the inner circle sampled in the summer campaign (■) and in the autumn sampling campaign (○) on total released ^{14}C activity in gaseous effluents, $A^{14}C$.

Only years with the spring (April) outage periods .

to asses the radiation dose rate (by consumption/ingestion):

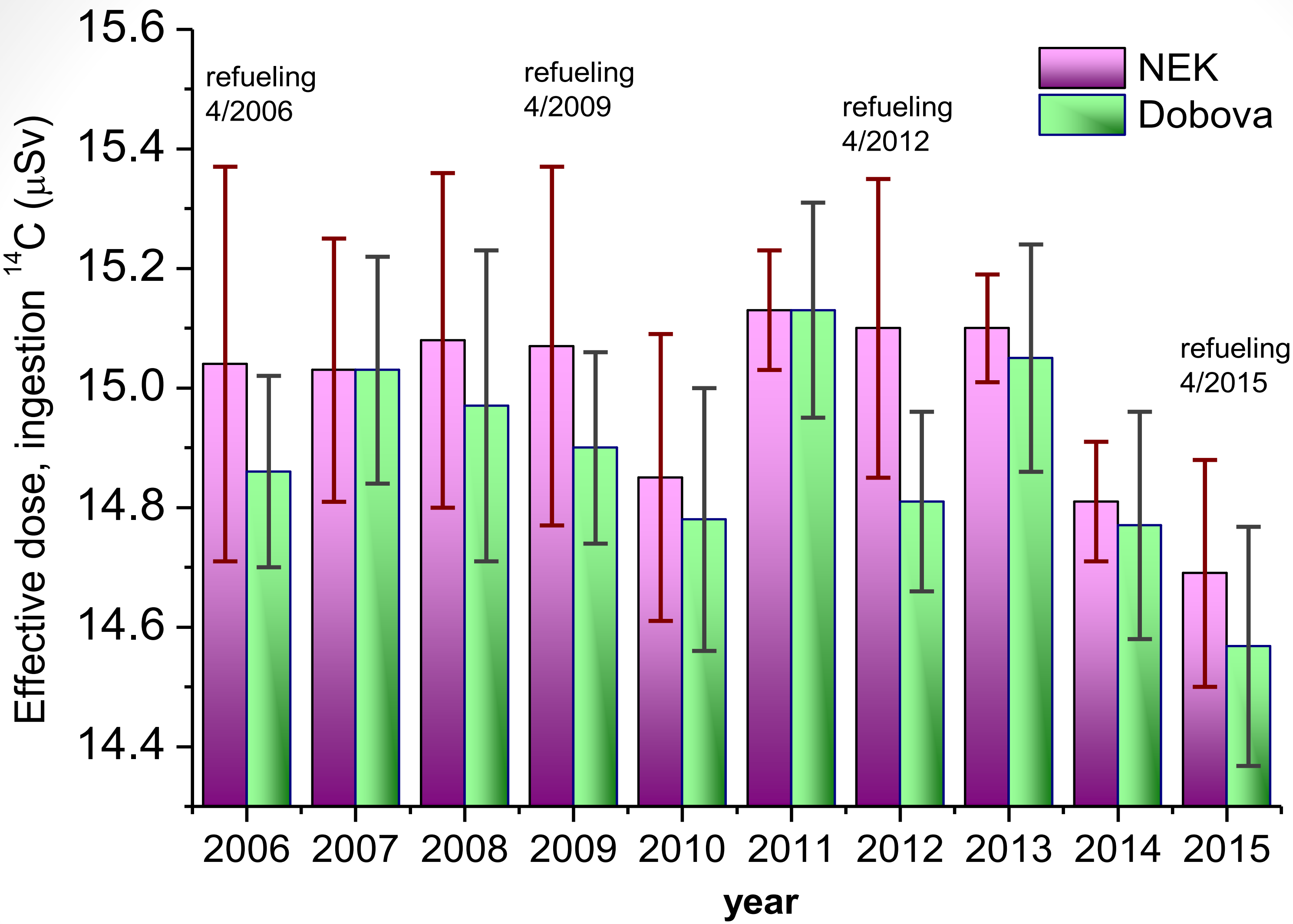
- activity conc. in foodstaffs, **$a^{14}C$ [Bq/kgC]**
- relevant consumption rates – daily uptake of C by food: 0.3 kg (ICRP, 1996)
- ICRP ingestion dose coefficients are needed

  $e = 5.8 \times 10^{-10}$ Sv/Bq

$$E = e \times a^{14}C \times m \times t$$

however, obtaining the consumption data for particular areas may not be simple;

luckily – the specific ^{14}C activity in all types of (terrestrial) foodstaff is the same



Comparison of annual effective doses due to ingestion of ^{14}C for population in the close environment of NEK and at the control point Dobova. No significant difference is observed.

CONCLUSIONS

- Increase of ^{14}C activity in atmospheric CO_2 and in plants was observed during and immediately after the refueling of the nuclear power plant
- Spatial distribution depends on the local wind rose and the distance from the exhaust of the plant ventilation system
- higher activities in plants collected after the spring refueling outage - intake of ^{14}C from gaseous effluents during the vegetation period
- The maximum increase of total annual dose to local population due to the release of ^{14}C from NEK in the years of spring refueling was estimated to be negligible and within the errors of the estimate