Харківський національний університет
імені В.Н. Каразіна

V. N. Karazin Kharkiv National University
School of Physics and Technology
Department of Nuclear and Medical Physics

Master's degree work

The influence of the radionuclide composition on the radiation characteristics of radioactive waste from Ukrainian nuclear power plants

Head **Rudychev V.G.**
PhD, Senior researcher

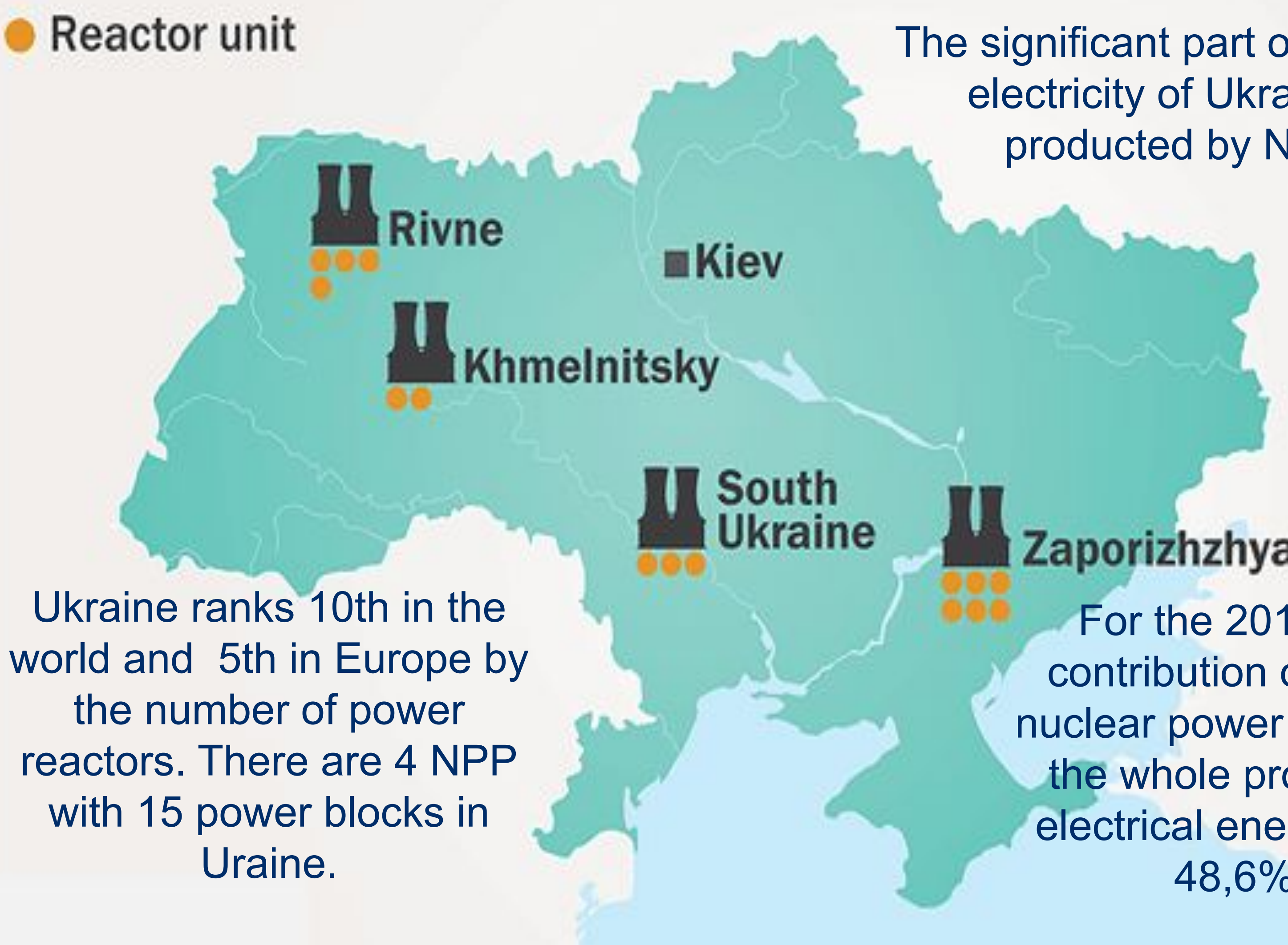
Student **Kaplii A.A.**

- Kharkiv 2015-

-1-

The aim of the present work :

The analyse of the nuclide composition contribution in changing of the radioactive waste characteristics (activity, radiotoxicity, the spectral composition and the radiation exposure) during handling and storage at Khmelnitsky NPP and Rivne NPP.



The significant part of the total electricity of Ukraine is producted by NPP.

Ukraine ranks 10th in the world and 5th in Europe by the number of power reactors. There are 4 NPP with 15 power blocks in Uraine.

For the 2014 the contribution of the 4 nuclear power plants in the whole produced electrical energy was 48,6%

During normal operation of nuclear power plants generate radioactive waste (RW).

Depends on the aggregation state:

- liquid (LRW)
- solid (SRW)
- gaseous (GRW)

Depends on the half-life

- short-lived
- Average-lived
- long-lived

Radioactive wastes are wastes that contain radioactive material.

Depends on the specific activity:

- Low-level (LLW)
- Intermediate-level(ILW)
- High-level (HLW)

Depends on the composition of the radiation :

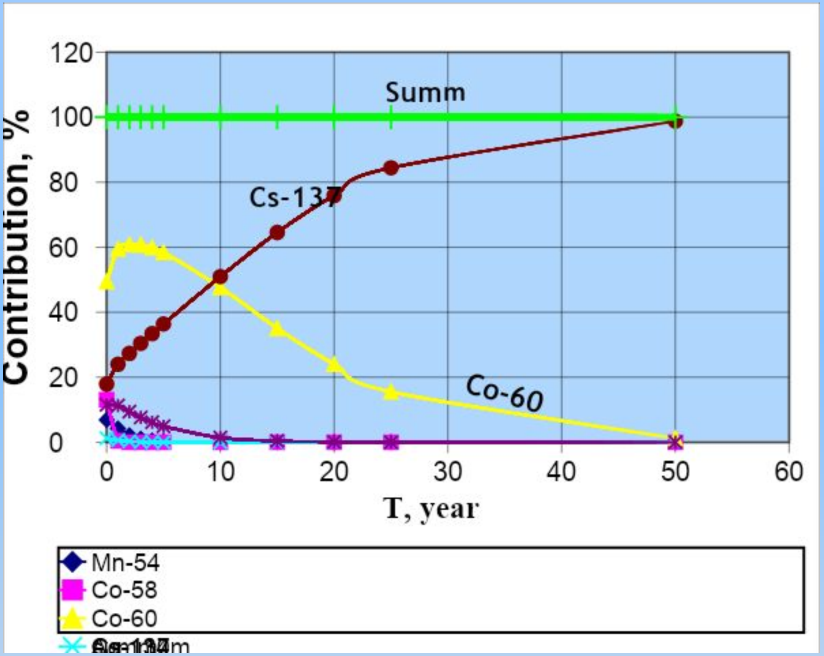
- α- radiator
- β- radiator
- γ- radiator
- neutron radiator

THE ISOTOPIC COMPOSITION OF SOLID RADIOACTIVE WASTE (SRW) AT THE KhNPP AND RNPP

The isotopic composition of SRW, which has formated during 2011-2013 at the Khmelnytsky and during 2011 at the Rivne Nuclear Power Plant is shown in Table. The same table shows the half-lives of these isotopes.

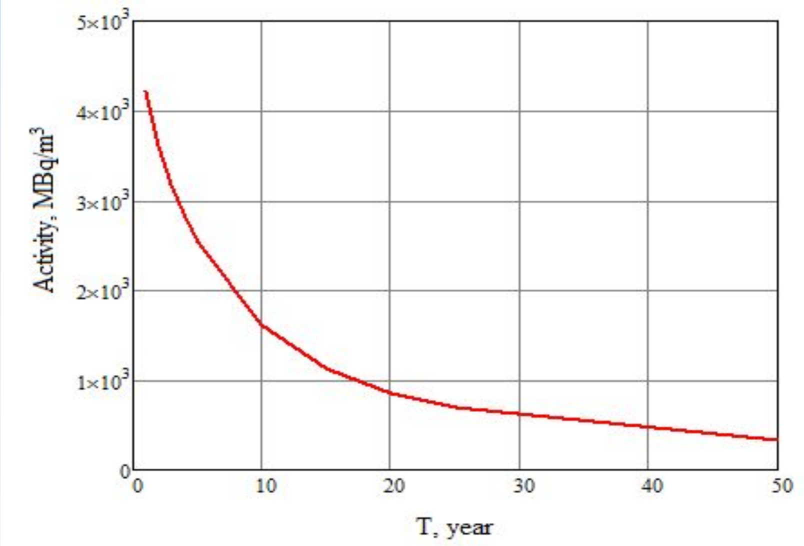
Nuclides	^{51}Cr	^{54}Mn	^{58}Co	^{60}Co	^{95}Zr	^{110m}Ag	^{124}Sb	^{134}Cs	^{137}Cs	Power plant, year
$T_{1/2}$, year	**0.076**	**0.85**	**0.19**	**5.27**	**0.175**	**0.685**	**0.164**	**2.06**	**30**	
Contents, %		6.9	13.07	49.4		1.25		11.5	17.88	KNPP 2011
		7.1	17.44	37.29		2.94		11.21	24.02	KNPP 2012
		9.38	10.4	45.92		0.78		9.25	24.27	KNPP 2013
	0.62	4.97	5.1	28.42	1.14	37.17	5.24	4.91	12.42	RNPP 2011

THE CHANGING IN THE ACTIVITY OF SRW KhNPP OVER THE TIME



Partial contribution of each element to the total activity which created SRW, formed at the KNPP during 2011 year.

The changing of total activity which generated by the six main radionuclides of the SRW at the KNPP, formed during 2011.



THE RADIOTOXICITY OF SRW AT THE KhNPP

Radiotoxicity of each nuclide i in the air or water is determined by the relation:

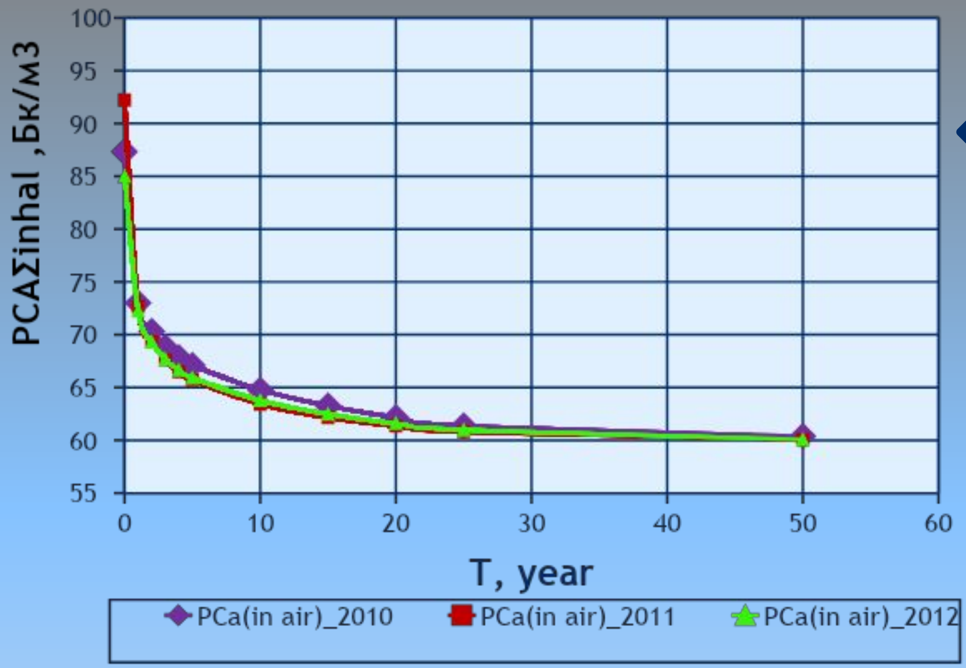
$$RT_i = A_i / DA_i ,$$

where A_i — activity of considering the amount of nuclide *i*; DA_i — maximum permissible activity of this nuclide in air or water.

- for air DA_i - PC_{AJ}^{inhal},
- for water Da_i – $PC_{БJ}^{ingest}$

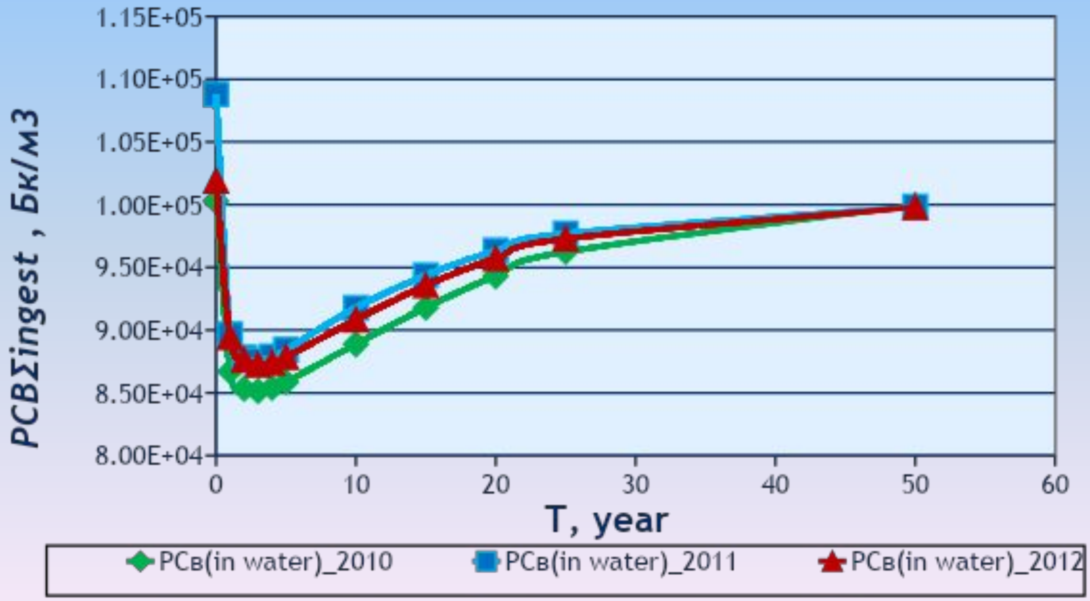
The values PC_{AJ}^{inhal} and $PC_{БJ}^{ingest}$ are taken from radiation safety standards-97, which correspond to the same international standards and are given in the table.

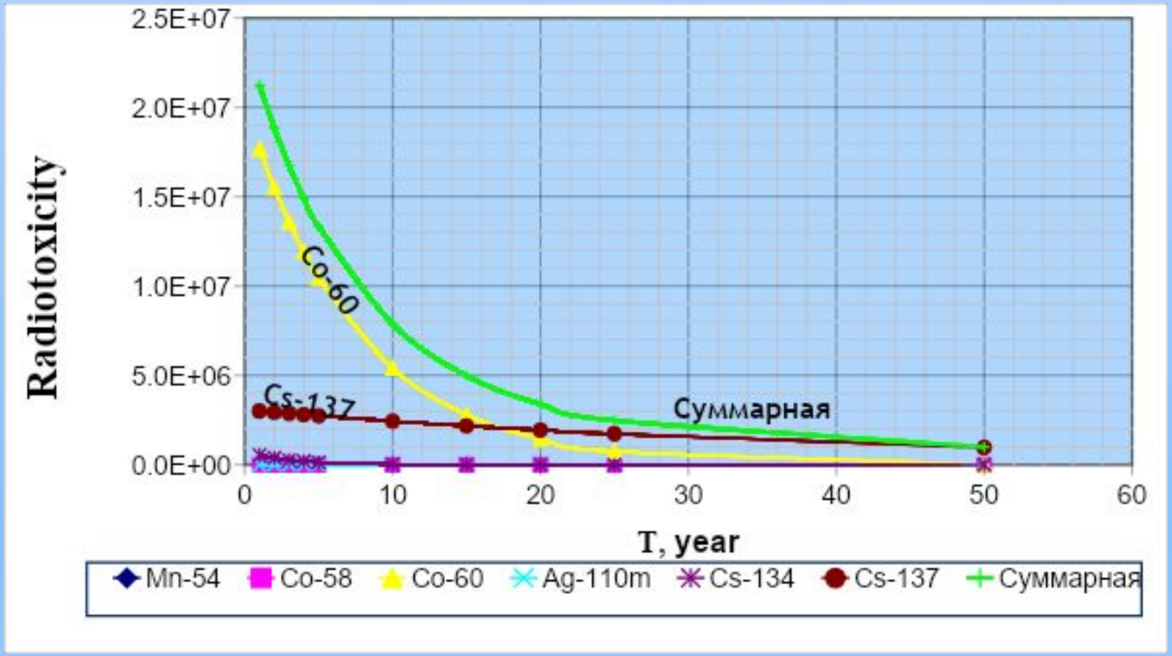
№	The isotopic composition:	The concentration of radionuclides **in the air** PC_{AJ}^{inhal},	The concentration of radionuclides **in the water** PC_{BJ}^{ingest},
1	**2**	**3**	**4**
1	Mn54	1.00E+03	8.00E+05
2	Co58	1.00E+03	6.00E+05
3	Co60	7.00E+01	8.00E+04
4	Ag110m	2.00E+02	2.00E+05
5	Cs134	1.00E+02	7.00E+04
6	Cs137	6.00E+01	1.00E+05



The changing of the concentration of the radionuclides mixture **in the air** over time at KhNPP during 2010-2012.

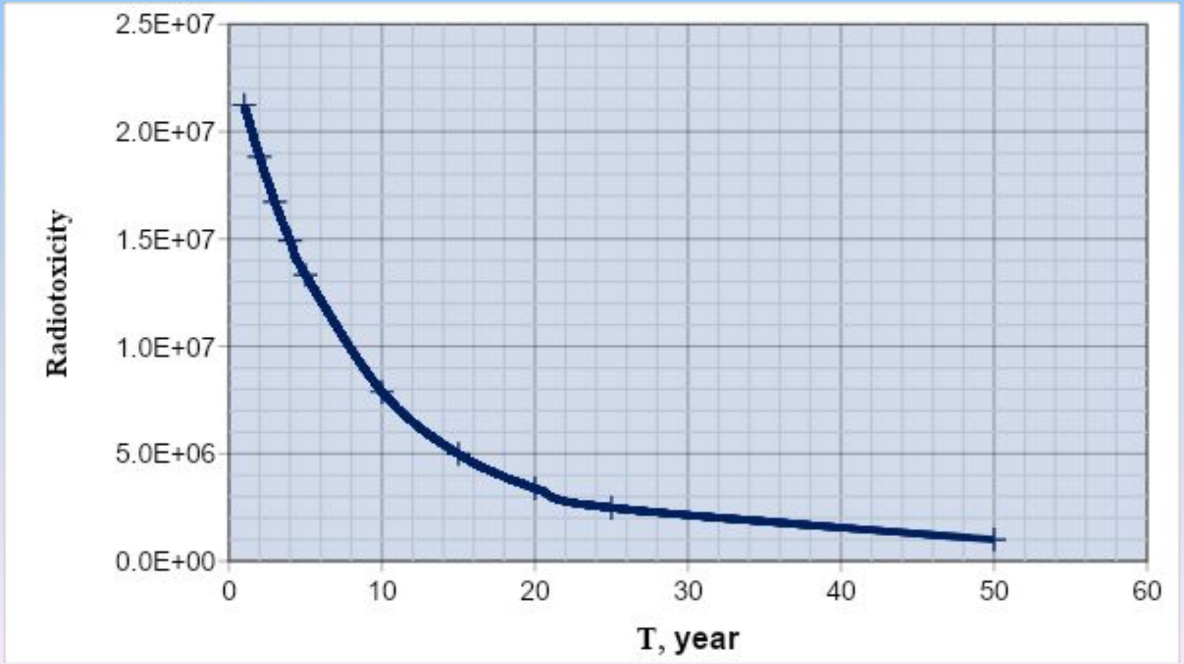
The changing of the concentration of the radionuclides mixture **in the water** over time at KhNPP during 2010-2012.

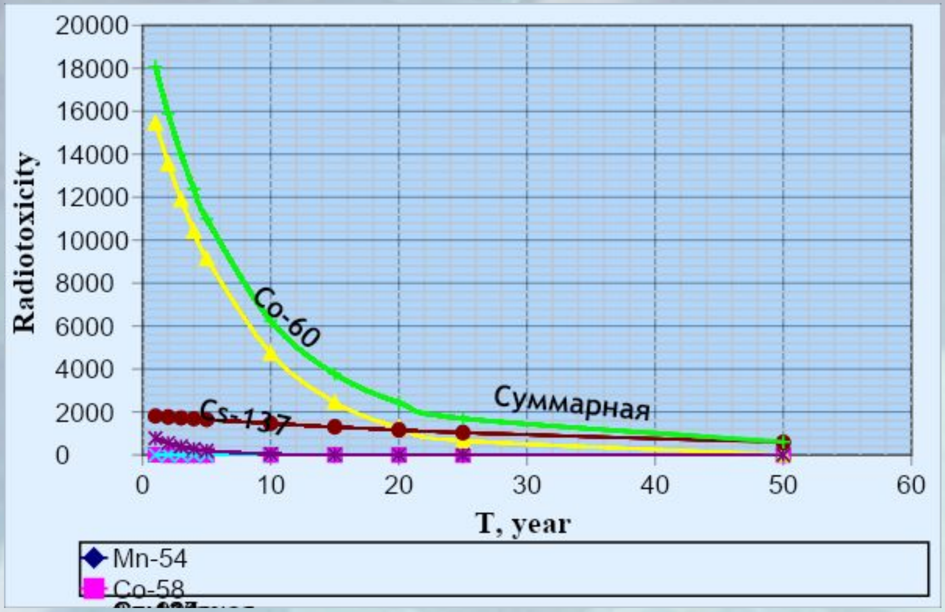




The changing of total radioactivity of the SRW during storage time **in the air** at the KhNPP formed in 2011.

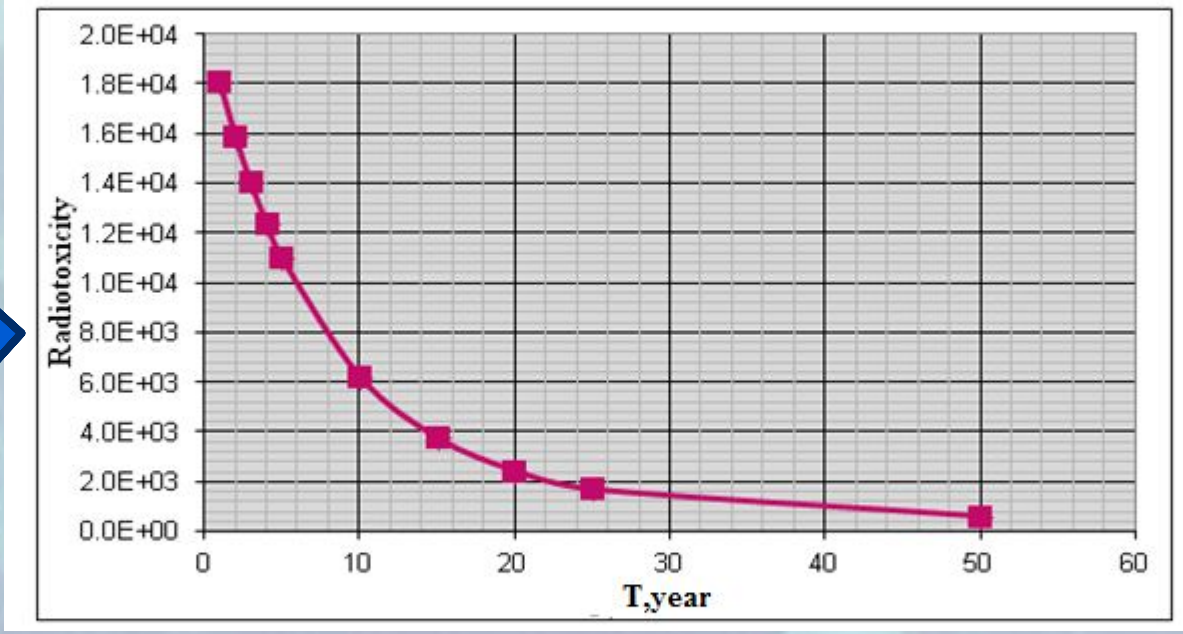
The contribution of each element in the change over time **in the air** radiotoxicity of SRW at the KhNPP formed in 2011.





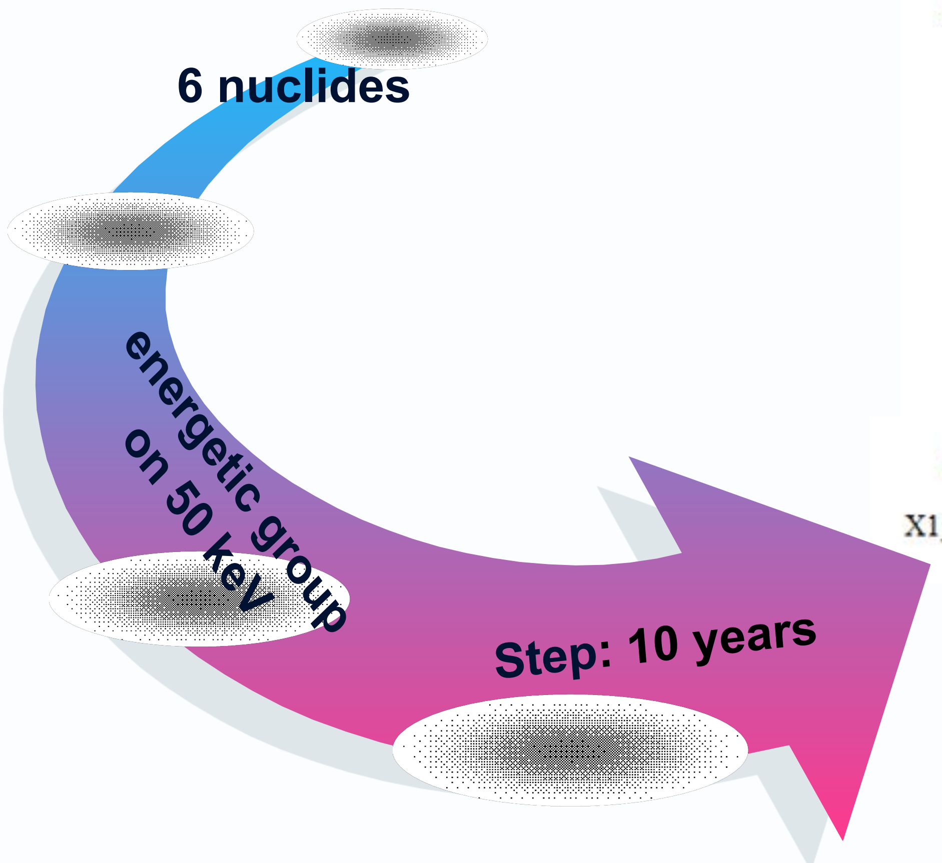
The contribution of each element in the change over time **in the water** radiotoxicity of SRW at the KhNPP formed in 2011.

The changing of total radioactivity of the SRW during storage time **in the water** at the KhNPP formed in 2011.



THE SPECTRAL DISTRIBUTION OF SOLID RADIOACTIVE WASTE AT THE KhNPP AND ITS DEPENDENCE ON THE TIME

For the investigated nuclide composition were calculated spectral distribution of gamma rays and analyzed its change over time in increments of 10 years.

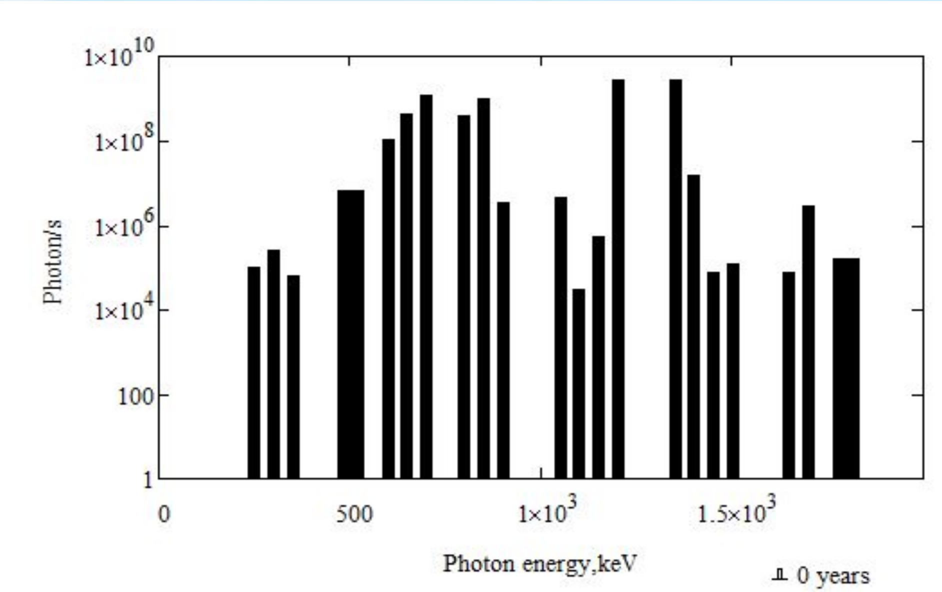


$$
\begin{aligned}
A(M) :=\ & \text{for } J \in 1..80 \\
& \quad C_J \leftarrow 0 \\
& N \leftarrow \text{rows}(M) \\
& \text{for } I \in 1..N \\
& \quad \left| \begin{array}{l} J1 \leftarrow \text{ceil}\left[\dfrac{M_{(I,1)}}{50}\right] \\ C_{J1} \leftarrow C_{J1} + M_{(I,2)} \end{array} \right. \\
& C
\end{aligned}
$$

$$T := 10$$

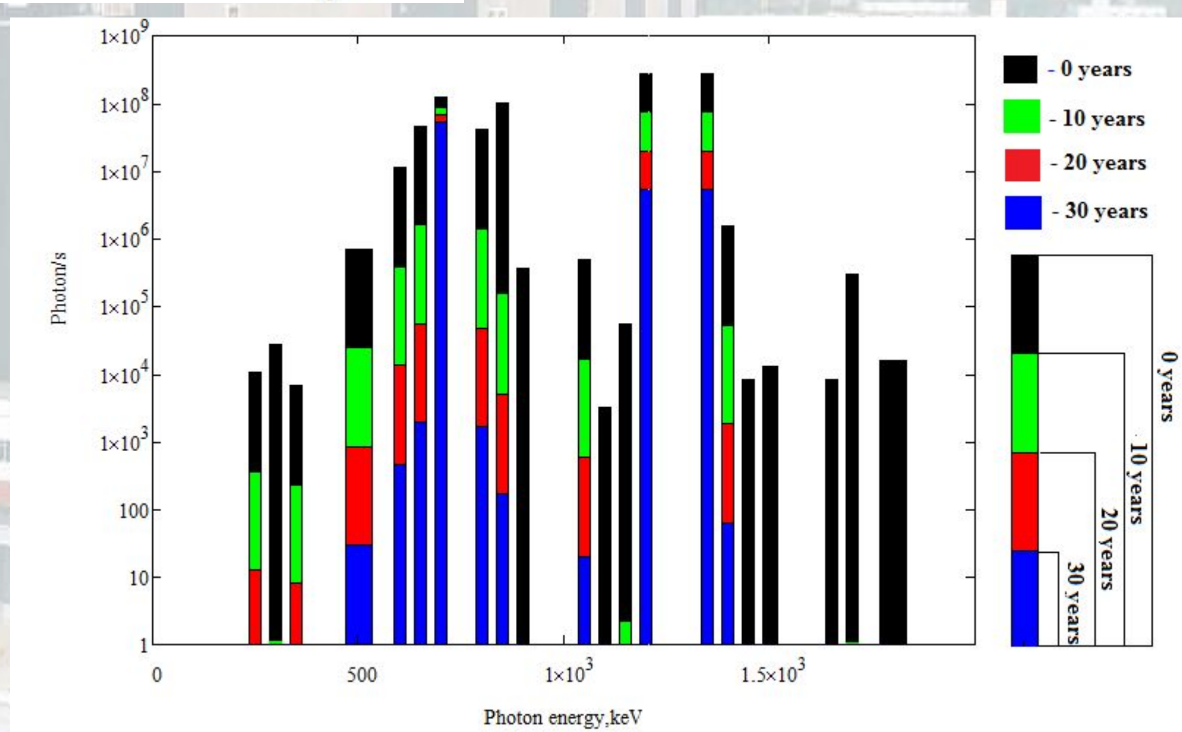
$$X1_J := A(\text{EIAg110m})_J \cdot \text{CAg110m} \cdot \exp\left(-0.693 \cdot \frac{T}{\text{TAg110m}}\right)$$

Fragments of the program.



The spectral distribution of the radiation at the initial time.

The total spectral distribution of radiation for the storage time 0,10, 20, 30 years.



CALCULATION OF THE DOSE RATE PRODUCED BY TWO METHODS:

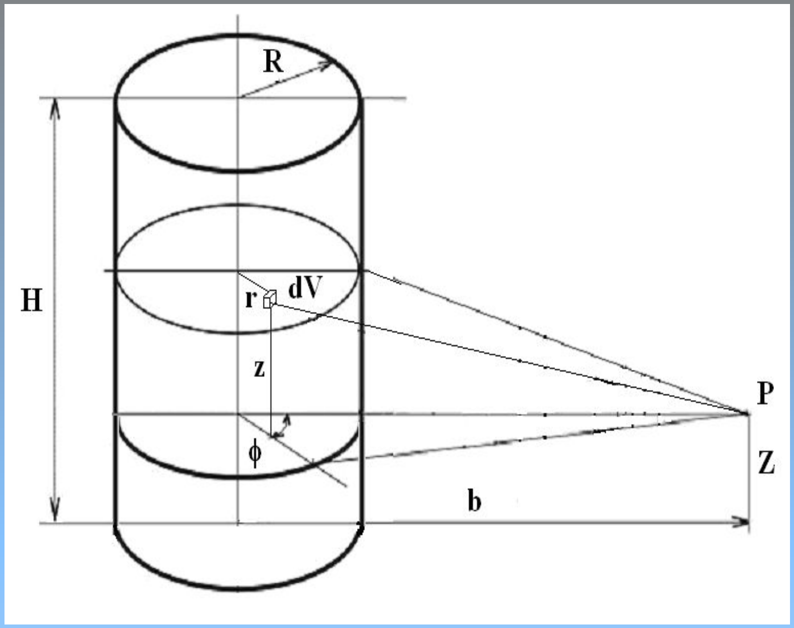
Methods of calculation

Monte Carlo method

Volume integration method

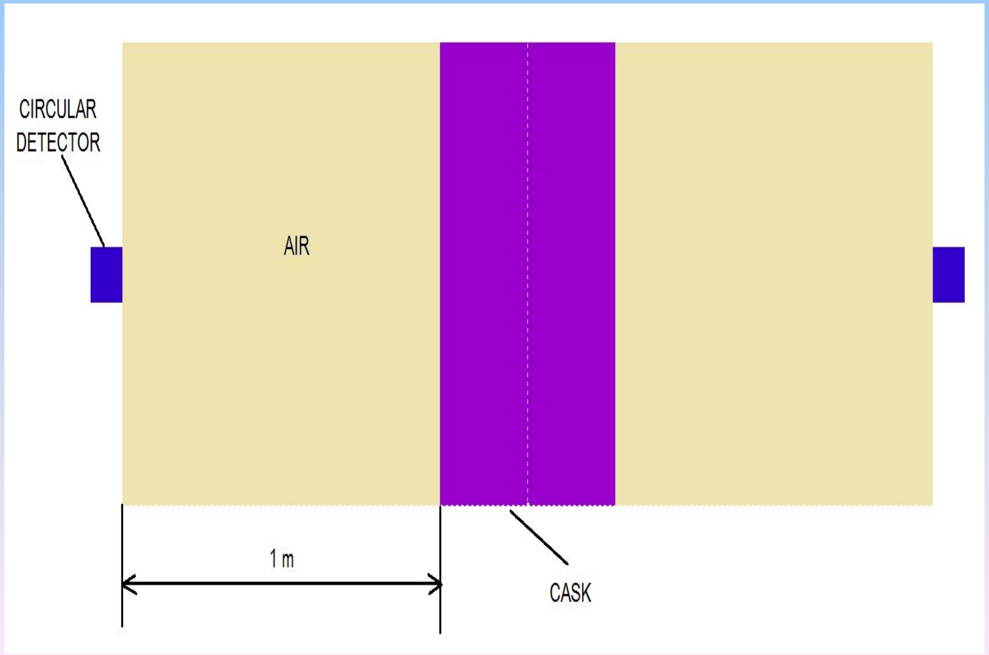
<u>The model container with SRW:</u>

- Form of the source is cylindrical cask
- height H=80 cm
- radius R=20 cm
- V_{cask} =200l



The geometrical demensions of a cylindrical volume source.

The package Penelope geometric model which used to calculate the characteristics of the radiation from a cylindrical source.



THE CALCULATION OF THE DOSE USING THE RADIATION CHARACTERISTICS OF INDIVIDUAL ENERGIES (NUCLIDES) CALCULATED WITH HELP THE MONTE CARLO METHOD.

- The spectral composition of the N-energy Eγ, will be determined by the relation: $$I(E)=\sum_{i=1}^{N} n_i(E_\gamma)\cdot I_i(E,E_\gamma),$$

where $n_i(E_\gamma)$ – the number of photons with energy E_γ,

$I_i(E,E_\gamma)$ – the distribution intensity of the photons generated by gamma rays with energies in the range of energies Eγ $0 < E < E_\gamma$.

- In our case, the isotopic composition of SRW presented 6th radionuclides. At the time of storage of SRW over 5 years the main contribution to the emission comes from ^{137}Cs and ^{60}Co.

These two main nuclides spectral composition of the radiation as a function of storage time T is determined by the following relation:

$$I_S(E,T)=n_{CS}(T)\cdot I_{CS}(E)+n_{CO}(T)\cdot I_{CO}(E),$$

where $n_{CS}(T)$ и $n_{CO}(T)$ – the number of photons which by emitted ^{137}Cs and ^{60}Co depend on the storage of radioactive waste.

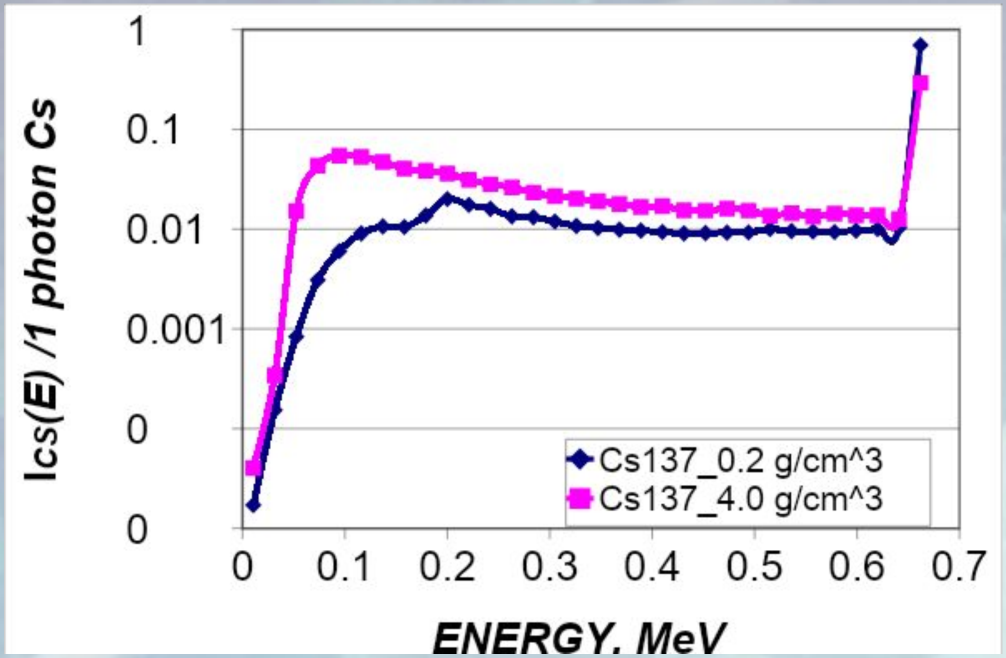
The output per 1 y-ray for cylindrical source with volume **200 l** and model filled with **concrete** elemental composition and densities of **0.2** and **4 g / cm^3,** was calculated with use Penelope package

```
SURFACE (   2)  Plane z=83.5
INDICES=( 0, 0, 0, 1, 0)
Z-SHIFT=( 8.350000000000000E+01,   0)
0000000000000000000000000000000000000000000000000000000000000000
SURFACE (   3)  Cylinder, r=27.60
INDICES=( 1, 1, 0, 0,-1)
X-SCALE=( 2.760000000000000E+01,   0)
Y-SCALE=( 2.760000000000000E+01,   0)
0000000000000000000000000000000000000000000000000000000000000000
SURFACE (   4)  Cylinder, r=127.60
INDICES=( 1, 1, 0, 0,-1)
X-SCALE=( 1.276000000000000E+02,   0)
Y-SCALE=( 1.276000000000000E+02,   0)
0000000000000000000000000000000000000000000000000000000000000000
```

Part of the file describes the geometry calculations.

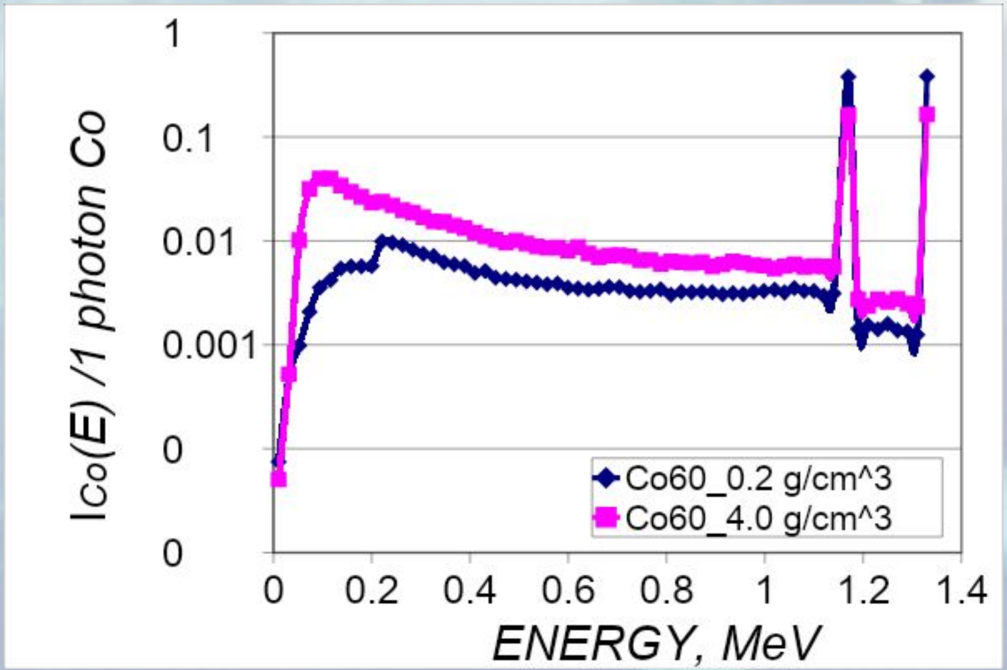
```
TITLE  Dose in a radioactive waste cask with air environment
       >>>>>>>> Source definition.
SKPAR  2        [Primary particles: 1=electron, 2=photon, 3=positron]
        Gamma-ray spectrum.

        SPECTR 570000 7.79E-03
        SPECTR 570000  -1
        SPECTR 610000 3.20E-02
        SPECTR 610000  -1
        SPECTR 670000 3.07E-01
        SPECTR 670000  -1
```

Part of the input file which defines the characteristics of the source.



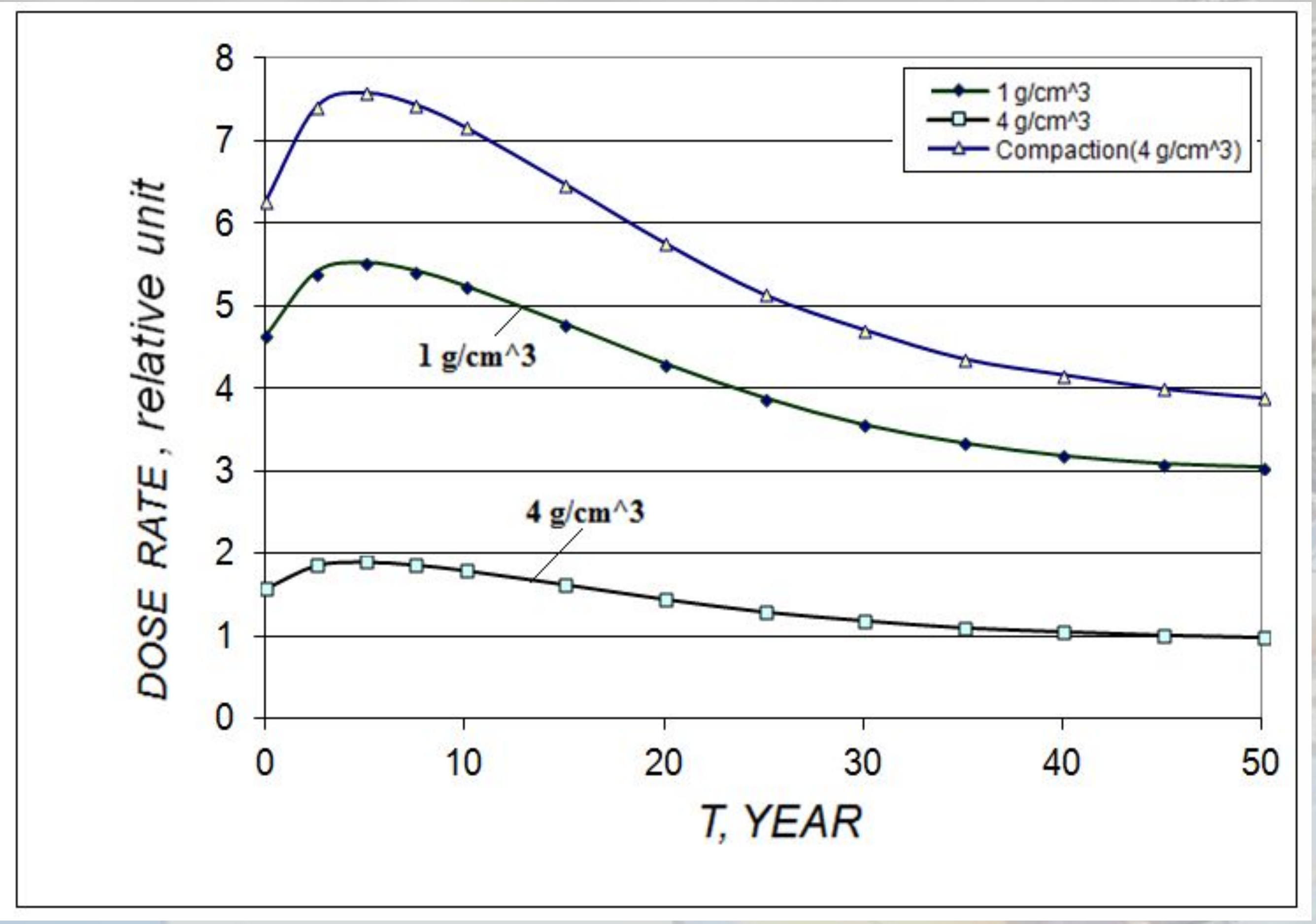
Spectral distribution of Cs, source densities of 0.2 and 4 g / cm^3

Spectral distribution of Co, source densities of 0.2 and 4 g / cm^3

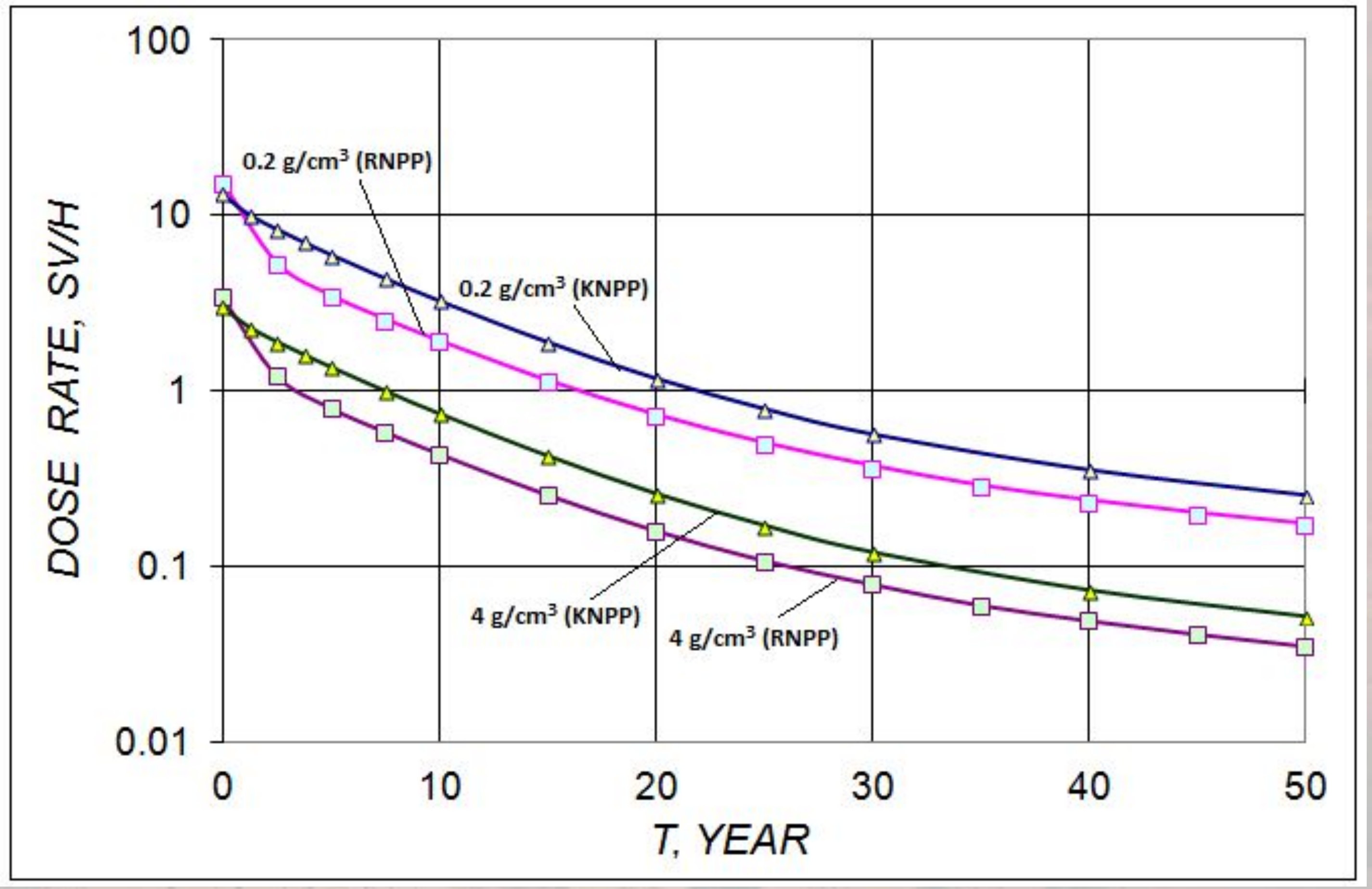


THE CHANGING OF THE DOSE RATE DURING COMPACTION:

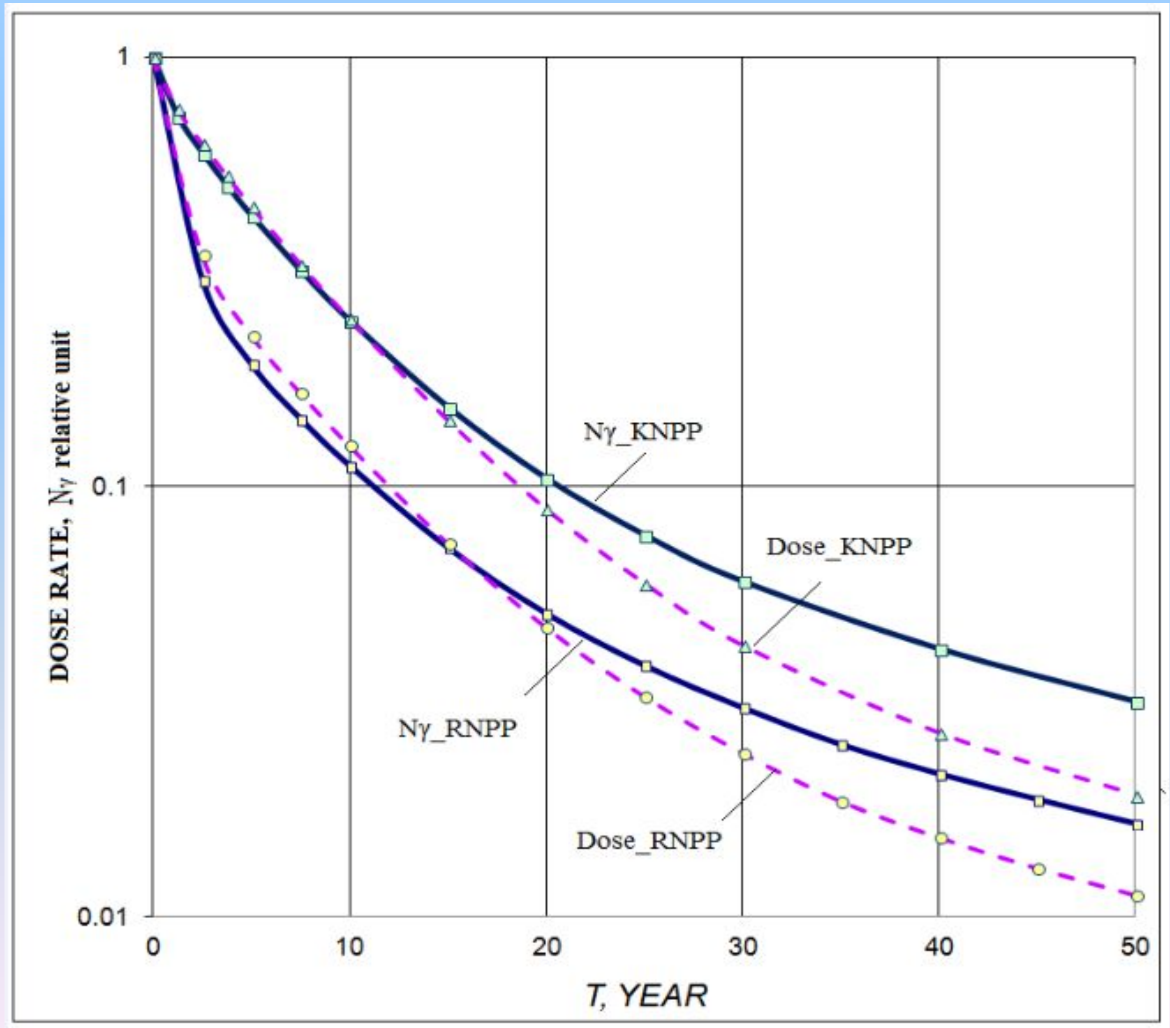
One of the widely used technologies for the reduction of waste is the waste compaction.



COMPARISON OF CHANGES IN DOSE RATE DEPEND ON THE STORAGE TIME FOR SRW DENSITIES :0.2 AND 4.0 g/cm^3 AT THE KhNPP AND RNPP



The changes in dose rate (in relative units) and the flux of gamma rays **depend on** the storage time and density of SRW 0.2 g/cm^3 at the KhNPP and RNPP



CONCLUSIONS:

- **The influence of the isotopic composition** of solid radioactive waste **on radiation characteristics** KhNPP was investigated;
- **The calculations of maximum permissible concentrations of radioactive waste in the air and water**, depending on the storage time of waste which are generated in 2010, 2011, 2012 at the KhNPP, was made;
- **For air and water medium it was calculated and analyzed** the dependence on the **radiotoxicity** time of waste generated during 2010 on the KhNPP;
- The changes in the **spectral composition of gamma-ray SRW** depend on the time was defined;
- With help of **volume integration and Monte Carlo methods was calculated dose rates** cylindrical source with model filling of radioactive waste at the KhNPP;
- **The analysis of changes in dose rate depend on the storage time** of radioactive waste at Khmelnytsky and Rivne NPP with different isotopic composition, was made.


Thank You!