Superposition of Potential Chemical Polluants and Radioisotopes and Their Influence Upon the Environment and Living Organisms

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Following the activities developed in a nuclear facility result gaseous and liquid radioactive effluents and radioactive solid waste. All these waste contain radioactive isotopes which are potentially pollutants for the environment. In the same time chemicals are, also, pollutants. According to the legislation, discharging of chemicals and radioactive liquid and gaseous effluents into the environment, should meet the requirements of the unrestricted discharge. However, what happens when several pollutants superpose: only chemical pollutants, or only radioactive pollutants, or chemical and radioactive pollutants? Such problems have been solved in this paper on the basis of the principle of critical energy.

Keywords: chemical pollutants; radioisotopes; superposition; environment, living organisms; principle of critical energy

The liquid effluents release into the environment must be preceded by qualitative and quantitative analysis in order to determine the contaminant radioisotopes and chemicals.

The effective values of radionuclide radioactive concentrations must be lover than its critical value. This depends on the place of discharge. If several radioisotopes, simultaneously or successively, are discharged into the environment, how is it determined whether that the critical state has been reached?

However, if one or more polluting chemicals and radioactive are being simultaneously discharged, how is it determined whether or not the situation is critical?

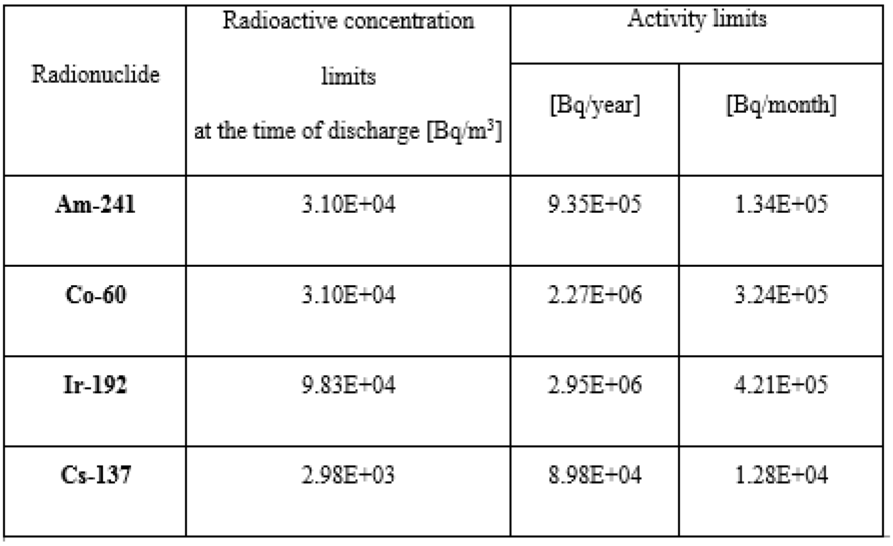
The current legislation states annual derived emission limits for each radioisotope (table 1) [1-4] that may be present in the environment or in living organisms.

The radioactive concentration of each radioisotope expressed in Bq/m^3 is taken into account in the decision-making process on further discharges into the environment of a certain radioisotope. For the discharge decision the effective radioactive concentration is compared with the maximum allowable concentration (table 1). However, if there are several radioisotopes, how is it assessed whether or not the limit state has been reached?

On other side the polluting chemical agents may deteriorate the environment, as well as living bodies. The maximum allowable (critical) concentrations for environmental factors (air, water, soil) are described in Table 2 [5-7]. Table 3 contains several limitations of chemicals concentrations for living bodies.

The effective concentration of a certain chemical pollutant must not exceed the maximum allowable concentration listed in table 2. Also in this case, is the problem of evaluation of the actual state of the polluted environment, simultaneous or successive, with more chemical pollutants. How can we state the maximum allowable of state in such cases of multiple chemical pollution?

In case of living bodies, pollution by one chemical agent is permitted if the concentration thereof is lower than a maximum allowable concentration listed in table 3. Another important problem is the simultaneous or successive pollution with several radioisotopes and many chemical



Radionuclide	Radioactive concentration limits at the time of discharge [Bq/m^3]	Activity limits	
		[Bq/year]	[Bq/month]
Am-241	3.10E+04	9.35E+05	1.34E+05
Co-60	3.10E+04	2.27E+06	3.24E+05
Ir-192	9.83E+04	2.95E+06	4.21E+05
Cs-137	2.98E+03	8.98E+04	1.28E+04

Table 1
MAXIMUM ALLOWABLE EMISSION LIMITS [1]

** email: vvjinescu@yahoo.com; Phone: (+40)21.4029193* agents. How do we determine, in this case, whether the limit state has been reached either for the environment or for the living bodies?

All these questions can be resolved, as will be shown below, using the principle of critical energy, a principle of Energonics.

Table 2

MAXIMUM ALLOWABLE CONCENTRATION OF SEVERAL CHEMICAL POLLUTANTS [5-7]

a – in air [5]

Physical or chemical pollutant	**UM**	Maximum Allowable Concentration (MCA)			The limit value for protection of ecosystems		
		The period of mediation					
		1 h	**24 h**	**1 year**	**1 h**	**24 h**	**1 year**
Sulphur dioxide	$\mu g/m^3$	350	125	-	-	-	20
Nitrogen dioxide and oxides of nitrogen	$\mu g/m^3$	200	-	40	-	-	24
Suspensions (PM_{10})	$\mu g/m^3$	50	-	40	-	35	28
Benzene	$\mu g/m^3$	-	-	5	-	-	-

b – in water [6]

Global indicators	**U.M.**	Waste water discharges in sewer networks	Waste water discharges into natural receivers
Pollutants discharged Maximum Allowable Concentration (MCA)			
Suspensions	mg/dm^3	350	35.0
Biochemical oxygen demand in 5 days (BOD5)	mg O_2/dm^3	300	25.0
Ammonia nitrogen (NH_4^+)	mg/dm^3	30	2.0
Sulphur and hydrogen sulphide(S_2^-)	mg/dm^3	1.0	0.5

c – in soil [7]

Physical or chemical pollutant	**U.M.**	Normal Values	Maximum Allowable Concentration (MCA)
A. Metals			
Arsenic (As)	mg/kg	5	15
Lead (Pb)	mg/kg	20	50
Nickel (Ni)	mg/kg	20	75
Mercury (Hg)	mg/kg	0.1	1
B. Elements			
Cyanide (free)	mg/kg	<1	5
Cyanide (complex)	mg/kg	<5	100
C. Aromatic and polyaromatic hydrocarbons, petroleum hydrocarbons			
Total aromatic hydrocarbons (AH)	mg/kg	<5	25

Polynuclear aromatic hydrocarbons(PAH):	mg/kg	<1	75
Total petroleum hydrocarbons	mg/kg	<100	200
D. Organic compounds organochlorine			
total chlorobenzenes	mg/kg	<0.1	5
Total polychlorinated biphenyls	mg/kg	<0.01	0.25
polychlorodibenzofurans	mg/kg	<0.0001	0.0001
E. Organochlorine pesticides and triazines			
Total Organochlorine pesticides	mg/kg	<0.2	1
Total triazines	mg/kg	<0.1	1

Table 3

MAXIMUM ALLOWABLE CONCENTRATION FOR LIVING BODIES OF SEVERAL CHEMICAL POLLUTANTS [5;8]

a – in air [5]				
Chemical agent pollutant	UM	The period of mediation		
		1 h	**24 h**	**1 year**
Sulphur dioxide	µg/m³	350	125	-
Nitrogen dioxide and oxides of nitrogen	µg/m³	140	-	32
Suspensions (PM_{10})	µg/m³	-	35	28
Benzene	µg/m³	-	-	5
b – in water [8]				
Chemical agent pollutant	**UM**			
Acrylamide	µg/dm³	0.10		
Arsenic	µg/dm³	10		
Benz(a)pyrene	µg/dm³	0.01		
Benzene	µg/dm³	1.0		
Boron	mg/dm³	1.0		

Calculation of radioisotope activity

To calculate of radioisotope activity, we denote the decay rate. It is measure of the number of disintegrations per unit time,

$$A = -dN / dt \qquad (1)$$

The decay rate is proportional to the number of radioactive atoms, N, $A \sim N$.

For periods of time (months), without discharge, the activity calculation is performed only using the radioactive decay law. The general equation for simple radioactive decay,

$$N = N_0 \cdot e^{-\lambda t}, \qquad (2)$$

where λ is the constant of radioactive decay,

$$\lambda = \frac{\ln 2}{T_{1/2}} = \frac{0.693}{T_{1/2}}, \qquad (3)$$

where t – the time (expressed in months in the specific case) and $T_{1/2}$ - the half-life of the radioisotope considered, also expressed in months.

The linearity of the decay curve in the semi-logarithmic graphical illustration shows the exponential nature of radioactive decay. Since $A \sim N$, we can use the equation of decay (E. Rutherford and F. Soddy, 1903):

$$A = A_0 \cdot \exp(-\lambda t), \qquad (4)$$

where A_0 is the activity of the radioisotope at the initial moment.

At the time (n) of one discharge, $A_{n,}$ it was used the relation [8],

$$A_n = A_{n-1} \cdot e^{-\lambda t} + A_{\text{discharge}}, \qquad (5)$$

where A_{n-1} is the activity of the radioisotope (existing in the environment) coming from previous discharges [Bq]; $A_{\text{discharge}} = C_{\text{rad}}$ x V (where V is the volume discharged, expressed in [l] and C_{rad} is radioactive concentration expressed in [Bq/l]).

Graphical illustration of activity variation after each discharge (at $t_0 = 0$; $t_1; t_2$) corresponds to the curves C_1;

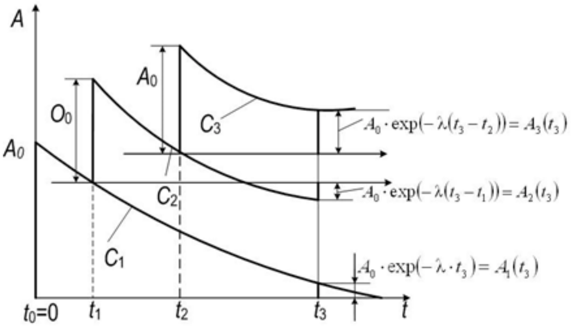


Fig. 1.

C_2 and C_3 (fig. 1). Each activity of radioisotopes decreases in time according to the general law (4).

At the time t_3, the activities corresponding to the three discharges for the same radioactive isotope becomes:

$$\left.\begin{array}{l} A_1(t_3)=A_0\cdot\exp(-\lambda\cdot t_3) - \text{for curve } C1; \\ A_2(t_3)=A_0\cdot\exp(-\lambda\cdot(t_3-t_1)) - \text{for curve } C2; \\ A_3(t_3)=A_0\cdot\exp(-\lambda\cdot(t_3-t_2)) - \text{for curve } C3. \end{array}\right\} \quad (6)$$

The total activity at a time *t*, for multiple discharges of the same radionuclide, results from summarizing the remaining activities from all discharges. By generalization, based on the preceding, it results that the total activity at one moment, *t*,

$$A_T(t)=\sum_i A_i(t)=\sum_{i=1}^{n}\left[A_i\cdot\exp(-\lambda_i\cdot t)\right] \quad (7)$$

or

$$A_T(t)=A_0\cdot\sum_{t_i=0}^{t_{n-1}}\exp\left[-\lambda\cdot(t_n-t_i)\right], \quad (8)$$

The influence of half-life time on the cumulation of activity for each radioactive isotope results from the relation (4) in which λ expression is replaced,

$$A_n=A_{n-1}\cdot\exp\left[-0.693\cdot\left(\frac{t}{T_{1/2}}\right)\right], \quad (9)$$

For a relatively long half-life time, for the *t* same value, the exponential is relatively small.

Derived math A_n in relation to time has the expression,

$$\frac{dA_n}{dt}=\left(-\frac{0.693}{T_{1/2}}\right)\cdot A_n. \quad (10)$$

which shows that time variation of activity A_n (decreasing in time), for the same time value *t*, is smaller than the half-life time (table 4) is higher.

Table 4

HALF-LIFE TIME OF SOME RADIOISOTOPES

	Radioisotope	$T_{1/2}$,
1.	**Am-241**	(432.6 ± 0.6) years [9]
2.	**Co-60**	(5.2711 ± 0.0008) years [10]
3.	**Ir-192**	(73.827 ± 0.013) days [11]
4	**Cs-137**	(30.5 ± 0.08) years [10]
5	H-3	(12.312 ± 0.025) years [10]

In case of local overlap, in time, of the radioactivity of all four radioisotopes listed in table 1, over a period of time, is obtained - by algebraic summation- the time variation of total activity. Total activity value, A_T, at the moment *t*, can be calculated by summing it with relation (7).

Local variation of the activity of a certain radioactive effluent (1), between the initial moment $(t=0)$ and the moment t_1, is (fig. 2),

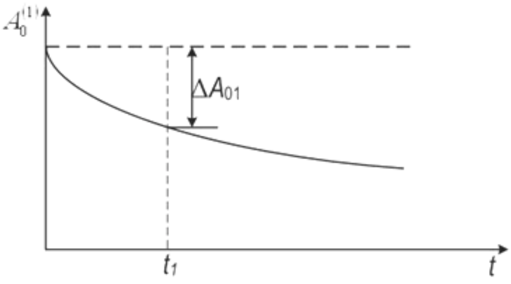


Fig. 2.

$$\Delta A_{01}^{(1)}=A_0^{(1)}\cdot\left[1-e^{-\lambda_1\cdot t_1}\right], \quad (11)$$

where $\lambda_1=\dfrac{0.693}{(T_{1/2})_{(1)}}$.

For another (2) radioactive effluent,

$$\Delta A_{02}^{(2)}=A_0^{(2)}\cdot\left[1-e^{-\lambda_2\cdot t_1}\right], \quad (12)$$

where $\lambda_2=\dfrac{0.693}{(T_{1/2})_{(2)}}$ etc.

Indices (1) and (2) refer to the values corresponding to the two effluents.

At the simultaneous action of the two effluents over time $0\ldots t_1$, total activity at the time t_1 is:

$$A_T=\left(A_0^{(1)}-\Delta A_{01}^{(1)}\right)+\left(A_0^{(2)}-\Delta A_{02}^{(2)}\right)= \\ =\frac{A_0^{(1)}}{\exp\left(\dfrac{0.693\cdot t_1}{(T_{1/2})_{(1)}}\right)}+\frac{A_0^{(2)}}{\exp\left(\dfrac{0.693\cdot t_1}{(T_{1/2})_{(2)}}\right)}, \quad (13)$$

wherefore it follows that at t=0, $t=0$, $A_T=A_0^{(1)}+A_0^{(2)}$ and $t_1\to\infty$, $A_T=0$.

Influence of uniform corrosion on material deterioration

The corrosive action, in the case of uniform corrosion, is determined on the basis of the relation expressing the correlation between the thickness of corroded material, Δs_{cs}, and the corrosion time, for each pair *material - corrosive agent* [12].

$$\Delta s_{cs}=k_z\cdot t^c \quad (14)$$

where k_z and *c* are constants of the corrosion process.

Corrosion deterioration of a material having initial thickness *s*, has the expression [13],

$$D_{cs}=\left(\frac{t}{t_t}\right)_{cs}^{c}, \quad (15)$$

where *t* is the contact time between the corrosive environment and the corroded body, and t_t – time up to full corrosion, of the entire thickness *s*.

Evaluation the critical state of the environment and living organisms by calculation

The critical state for a certain body is reached when specific energy (energy density), accumulated due to external actions, achieve a critical value, depending on the particularities of that body.

Such problems have been resolved in other cases, corresponding either to loads cumulation [14,15], or some load superposition [16-21], upon a certain body (solid body, environmental, living organism...)

a. *Solving of superposition and/or cumulations problems of some loads effects*, In the general case of non-linear behaviour of matter, is done using the principle of critical energy [22-24].

According to this principle, the critical state is reached when the total participation of the specific energies involved $P_T(t)$, becomes equal to critical participation, $P_{cr}(t)$, both are time-depending, *t*,

$$P_T(t) = P_{cr}(t). \tag{16}$$

Total participation corresponding some loads, S_i, has the expression [25],

$$P_T(t) = \sum_i \left(\frac{S_i}{S_{i,cr}} \right)^{\alpha_S + 1}, \tag{17}$$

where $S_{i,cr}$ is critical value for S_i, for that type of load, and $\alpha_s = 1/k_s$, where k_s is the exponent on the law of behaviour of the material body loaded,

$$S_i = M_S \cdot e_i^{k_S}, \tag{18}$$

where e_i is the load effect, M_s and k_s – material constants.

The critical participation has the following expressions [15;26]:

$$P_{cr}(t) = \begin{cases} P_{cr}(0) - D_T(t) - P_{rez} \ \text{– for inert bodies (lifeless bodies);} \\ \\ P_{cr}(0) - D_T(t) - W_n + P_{tr}(t) \ \text{– for living matter,} \end{cases} \tag{19}$$

where $P_{cr}(0)$ is the initial value of critical participation, at t = 0, and expresses the statistical distribution of physical characteristics values.

Generally, $P_{cr}(0) \in \left[P_{cr,\min}(0); P_{cr,\max}(0) \right]$ with $P_{cr,\min}(0) > 0$ and $P_{cr,\max}(0) \leq 1$. If the physical characteristics are deterministic values, then $P_{cr}(0) = 1$.

$D_T(t)$ is the total damage (or deterioration), a dimensionless value,

$$D_T(t) = \sum_i D_i(t), \tag{20}$$

where $D_i(t)$ is the deterioration of matter due to cause *i*; for example, due to corrosion, erosion, creep, vibration, hydrogen action, neutron action, magnetic field, radiation action, chemical pollutants etc.

By manufacturing, in the engineering components there are induced residual stresses, σ_{res}, to which corresponds the participation,

$$P_{res} = \left(\frac{\sigma_{res}}{\sigma_u} \right)^2 \cdot \delta_{res}, \tag{21}$$

where σ_u is the ultimate stress and $\delta_{res}=1$ if the residual stresses act in the direction of the process taking place and $\delta_{res}=-1$ if not.

For the living bodies the participation corresponding to the weakness due to lack of vitamins, oligoelements etc. is introduced; it is dimensionless. The total participation to the weakness is,

$$W_n = \sum_j W_{n,j}, \tag{22}$$

where $W_{n,j}$ is the participation to the weakness due to cause *j*.

$P_{tr}(t)$ is the participation of specific energies through the treatments, medicines etc.; it is a subunit dimensionless size, which can be: positive if it helps to increase the body's resistance, null if it has no effect and negative if it decreases body resistance, in the given case of load.

The total participation of the specific energies $P_T(t)$ - dimensionless value - express the load level of material body at a given time *t*. The critical participation $P_{cr}(t)$ - dimensionless value - express the resistance of the material body at a given time *t*.

Therefore, if,

$$\begin{aligned} &P_T(t) < P_{cr}(t) \text{ - the loading is subcritical;} \\ &P_T(t) \geq P_{cr}(t) \text{ - the loading is critical or overcritical.} \end{aligned} \tag{23}$$

Deterioration of the environment or of a living organism, by action:

– a pollutant, the concentration $c_{p,i}$ whose the maximum permissible concentration in the environment $c_{p,imax}$ is calculated with the relation,

$$D_p(c_{p,i}) = \left(\frac{c_{p,i}(t)}{c_{p,i,\max}} \right)^{\alpha_{p,i} + 1}, \tag{24}$$

where $\alpha_{p,i} = 1/k_{c_i}$, k_{c_i}, derives from the general law of non-linear behaviour of the body upon load with a pollutant,

$$c_{p,i}(t) = M_{c_p} \cdot e_{p,i}^{k_{p,i}}(t), \tag{25}$$

where $e_{p,i}$ is the effect of the pollutant on the environment, living organisms, plants etc.; M_{cp} and $k_{p,i}$ - are constants relating with the pollutant.

- more pollutants; the total deterioration due to pollutants is,

$$D_{T,p}(c_p) = \sum \left(\frac{c_{p,i}(t)}{c_{p,i\max}} \right)^{\alpha_{p,i} + 1}; \tag{26}$$

- radioactive by radioisotope with activity $A_k(t)$, the deterioration can be calculated with the relation,

$$D_k(A_k) = \left(\frac{A_k(t)}{A_{k,\max}} \right)^{\alpha_{A,k} + 1}. \tag{27}$$

Here $A_k(t)$ is the activity measured at the time *t*, and $\alpha_{A,k} = 1/k_{A,k}$ where $k_{A,k}$ is the exponent of the law, function of power, expressing the connection between the cause (A_k) and its effect, $e_{A,k}$, on the analysed material body (inert body, air, water, soil, a living organism etc…),

$$A_k(t) = M_{A,k} \cdot e_{A,k}^{k_{A,k}}, \tag{28}$$

where $M_{A,k}$ and $k_{A,k}$ are the constant of the irradiated material body;

– radioactive by several radioisotopes; total deterioration is,

$$D_{T,k}(A_k) = \sum_k \left(\frac{A_k(t)}{A_{k,\max}} \right)^{\alpha_{A,k} + 1} \tag{29}$$

It should be noted that in previous relationships either exponents $\alpha = 1/k$ corresponds to a quasistatic load. If the load has a shock character, then any of these exponents is null, $\alpha = 0$.

Where, in analysing the resistance of the body are using deterministic values of physical characteristics ($P_{cr}(0) = 1$) the relations (19) becomes

$$P_{cr}(t) = \begin{cases} 1 - D_T(t) - P_{rez}, \text{ for inert bodies (lifeless bodies);} \\ \\ 1 - D_T(t) - W_n + P_{tr}(t), \text{ for living matter} \end{cases} \qquad (30)$$

The higher the deterioration to the body (inert body, living matter, environment ...), its resistance to external loads becomes lower. If at certain given moment t_1, the deterioration $D'_T(t_1) > D_T(t_1)$ the body resistance is characterized by critical participation $P'_{cr}(t) < P_{cr}(t)$ (fig. 3).

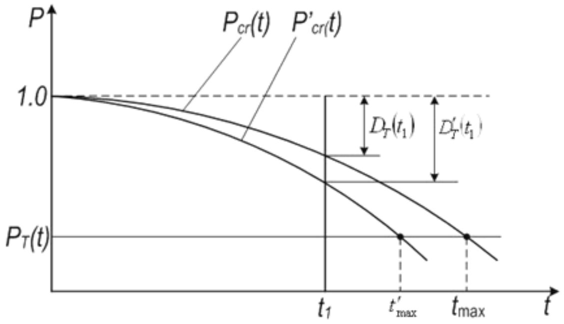


Fig. 3. The variation in time of critical participation if the deterioration grows slowly over time $P_{cr}(t)$ or rapid $P'_{cr}(t)$

For a certain total participation value PT(t), it results that the duration of the load until the total deterioration is t_{max} for $P_{cr}(t)$ and $t'_{max} > t_{max}$ for. In other words, lifetime is strongly affected by the increase in time of body deterioration.

Superposition or cumulation of loadings and synergy

Each load *Y* determine a certain effect *X* plus a thermal effect X_{th}. Two loads applied simultaneously, Y_1 and Y_2, determine the effects X_1 and X_2 plus a thermal effect.

If X_1 and X_2 are effects of the same nature (for example: deformations or rotations, or magnetic inductions, or corrosion, etc ...) the total effect, *X*, is equal to the algebraic sum of their partial effects $X = X_1 + X_2$, only if X_1 and X_2 have the same unit of measure, and the behaviour of the body loaded is linear ($Y = M_\sigma \cdot X$, where M_σ is constant of the material).

Generally, the behaviour of matter is non-linear (relations (12)÷(16), (23), (26)) that means the total effect is different from the sum of partial effects [27], $X \neq X_1 + X_2$.

This observation led to clarifying the problem of the synergistic effect in case of superposition or cumulation loads. Usually, by synergistic effect it is understood that the total effect is greater than the sum of the particular effects ($X > X_1 + X_2$). It has been demonstrated [27] that the total effect depends not only on particular effects, but also by the exponent of the material behaviour law, when it is non-linear ($Y = M_y \cdot X^k$, where M_y and $k \neq 1$ are the constant of the loaded material). In case of radioisotopes and corrosive substances the exponents in the behaviour law (12) and (23) may be different from 1.0; in these situations $X \neq X_1 + X_2$.

If these exponents are supra unitary ($k > 1$), negative synergistic effects are obtained ($X < X_1 + X_2$), while the exponents are subunits ($k<1$) synergistic positive effects are obtained ($X > X_1 + X_2$). These results in the importance of knowing exactly the law of behaviour of the matter loaded.

The evaluation of the synergistic effect was done at the macroscopic level [27], as well as at the molecular level [28]. Molecular evaluation is particularly important in analysing the influence of any load on living organisms.

Example of calculation

Consider polluted water at with two chemical substances (Nitrogen and Sulphides and Hydrogen sulphide S^{2-}) and with three radioisotopes (^{241}Am, ^{60}Co, ^{192}Ir), as in tables 5 and 6.

It has to be calculated: - the partial deteriorations and the total deterioration produced at the moment t = 0 for the aquatic environment and the value of these deteriorations after one year;

a. The total deterioration produced at the moment t=0.

The deterioration produced by the chemical substances at the moment of discharge (t=0) according to eq. (24), with $\alpha_{pi} = 0$, is

Table 5

MAXIMUM ALLOWABLE CONCENTRATIONS AND CONCENTRATIONS OF CHEMICALS DISCHARGED

Chemical agent pollutant	U.M.	Maximum allowable concentration [6]	Concentration value of pollutant at discharge time
Nitrogen (N_x)	mg/dm³	10	1.68
Sulphides and hydrogen sulphide (S^{2-})	mg/dm³	0.5	0.020

Table 6

MAXIMUM ALLOWABLE CONCENTRATIONS AND CONCENTRATIONS OF RADIOISOTOPES DISCHARGED

Radioisotope	Maximum allowable radioactive concentration [Bq/m³]	Concentration value of radioisotopes at discharge time [Bq/m³]
^{241}Am	3.10E+04	4.07E+03
^{60}Co	3.10E+04	1.47E+04
^{192}Ir	9.83E+04	1.43E+04

$$D_T\left(c_p\right)=\sum\left(\frac{c_{p,i}(t)}{c_{p,i,\max}}\right)^{\alpha_{pi}+1}=\frac{c_p(N_x)}{c_{p,\max}(N_x)}+\frac{c_p(S^{2-})}{c_{p,\max}(S^{2-})}=$$

$$=\frac{1.68}{10}+\frac{0.02}{0.5}=0.208.$$

The deterioration produced by the radioisotopes at the moment of discharge (t=0):

$$D_T(A)=\frac{A(^{241}Am)}{A_{\max}(^{241}Am)}+\frac{A(^{60}Co)}{A_{\max}(^{60}Co)}+\frac{A(^{192}Ir)}{A_{\max}(^{192}Ir)}=;$$

$$=\frac{4.07\cdot10^3}{31\cdot10^3}+\frac{1.47\cdot10^4}{3.1\cdot10^4}+\frac{1.43\cdot10^4}{9.83\cdot10^4}=0.7509$$

The total deterioration for environmental at (t=0)

$$D_T(t=0)=D_T(c)+D_T(A)=0.208+0.7509=0.9589.$$

Since $D_T(t=0)<1$ - the situation is considered acceptable, being uncritical

b. The total deterioration after one year (t=1 year).

The deterioration produced by the chemical substances, in the hypothesis that they were not processed by some living organisms, we will consider it the same as the one at t=0:

$$D_T'(c)=0.208.$$

The deterioration produced by the radioisotopes after one year, considering the decay law (2) and the eq. (29), with $a_{A,k}$ = 0, is:

$$D_t'(A)=\frac{A'(^{241}Am)}{A_{\max}(^{241}Am)}+\frac{A'(^{60}Co)}{A_{\max}(^{60}Co)}+\frac{A'(^{192}Ir)}{A_{\max}(^{192}Ir)}=$$

$$=\frac{4.06\cdot10^3}{31\cdot10^3}+\frac{1.29\cdot10^4}{3.1\cdot10^4}+\frac{0.04\cdot10^4}{9.83\cdot10^4}=$$

$$=0.13108+0.41607+0.00434=0.5514,$$

in which it was taken into account that the half-life time for ^{241}Am is 432.6 years and for ^{60}Co is 5.27 years (Table 4).

The total deterioration of the environmental after one year,

$$D_T'(t=0)=D_T'(c)+D_T'(A)=0.208+0.5514=0.7594.$$

It results that the maximum danger is at t=0 and decreases only as a result of decreased activity of the discharged radioisotopes. In our case, the effect of decreasing total activity is only caused by the decrease in ^{192}Ir activity.

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