APPROACH TO REGULATORY CONTROL COMPLETE RELEASE FOR LANDS IN THE CHORNOBYL EXCLUSION ZONE USING DENSITY OF RADIOACTIVE CONTAMINATION

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UNCERTAINTIES OF AVERAGED RADIOLOGICAL INDEXES (INSTEAD OF INTRODUCTION)

Formation dose to human can be considered as a multifactor process, when each forming component is subjected to fluctuations. As a result a certain distribution of the dose to human corresponds to a static set of dose forming entry parameters. The use of average dose values, especially when they are close to reference levels or to the dose limits, can mean that a considerable part of distribution exceeds predetermined levels.

Application of dose constraint concept is accepted practice for preventing such "non-account" [1]. The dose constraint is individual dose related to an exposure source and it is used for limitation of variants which are taken into account in a protection optimization process. The dose constraint is used for providing the confidence that external and internal doses from all controlled sources of exposure do not exceed the dose limit. The dose constraint can be numerically defined as a higher boundary of the preset confidence interval of the dose distribution.

Substantiation of the preset confidence interval is a fundamental dilemma for establishing the dose constraint. On one hand, this value has to be sufficiently high for providing a necessary level of protection. On the other hand, the confidence interval widening is limited by corresponding nonlinearly rising financial costs.

A procedure of reference level (RL) calculation from [2] is used in this work for establishing the preset confidence interval. In the mentioned work RL is set as 99% percentile of actual data, according to [3] where regulation of *potential* exposure is introduced. Thus, a probability value, that complements the *reference probability* 1% of critical event (i.e. 99%), is defined as sufficient protection level in view of stochastic nature of dose forming factors. The ratio between the dose constraint and average dose value is called a safety (or coverage) factor. According to international standards [1] the coverage factor is to be used for estimation of the individual dose constraint for members of the public.

Dose calculations are usually carried out with use of so called dose conversion coefficients (DCC), which link radiological environment parameters (as a rule that is the density of radioactive contamination of surface soil layer) with the annual dose to an individual staying in this environment. For estimation of dose to members of the public living in conditions of prolonged exposure from the Chornobyl radioactive fallout taking into account both average and maximal values of DCC is needed. The following dose forming factors are considered in this work:

- External exposure from ^{137}Cs;
- Peroral intake of ^{137}Cs and ^{90}Sr via food chain;
- Inhalation intake of transuraniums (TRU) for both natural and technogenic re-suspension.

EXPOSURE FACTORS

External exposure from ^{137}Cs

Within framework of international joint research in 1995-98 [4] everyone from a group of inhabitants of the exclusion zone was supplied with three luminescent glass dosimeters Toshiba GD-400 for a period from one to three months [5]. One of the three dosimeters was being carried pinned to outer clothing of an individual, the second one was placed inside a house, and the third one was located outdoor (in a yard). As a result, three sets of doses were obtained: individual external doses, house doses and outdoor doses. In general, 273 inhabitants from 23 settlements took part in the research in 1997-1998. The minimum individual external dose (re-calculated per year) made 603 $\mu Sv \cdot year^{-1}$, and maximal – 18321 $\mu Sv \cdot year^{-1}$ (village Ragivka, 2058 μSv for 41 day of exposure). The minimum outdoor dose made 678 $\mu Sv \cdot year^{-1}$, and maximal – 7706 $\mu Sv \cdot year^{-1}$.

Using the obtained dose information, correlations of the individual dose, the house dose and the outdoor dose with the ^{137}Cs soil radioactive contamination were built [6]. As a result, correlation between the individual dose rate and the density of radioactive contamination of ^{137}Cs was found of 0.7 $\mu Sv \cdot year^{-1}/(kBq \cdot м^{-2})$ that rather good conforms to literature sources [7], as well as the contribution into the individual dose from natural background was assessed at level of 0.9 $mSv \cdot year^{-1}$. Taking into account the three types of dose measurements the shielding factor for houses was assessed at level 4.8. Also so called regime coefficient was assessed at level 0.39. Statistical analysis of the dose distribution enables to determine the coverage factor (99% percentile of measured dose/approximated value ratio) at level 3.

The temporal trend of the gamma dose rate is also an important dose forming factor for the public in the future. Since ^{137}Cs decay is described by exponent, its account is trivial. Therefore numerical assessment of other processes is more important. Those processes causing in general the decrease of the dose rate are named sometimes as "auto-cleaning" or "vertical deepening" processes.

As an example, Golikov's model that is quoted in [8] can be considered here. According to this model the descent rate of the external exposure from ^{137}Cs of the Chornobyl fallout at Novozybkov area (Briansk region, Russia) on virgin lands in 1991-2000 was approximately $10\% \cdot year^{-1}$, including radioactive decay. After subtraction of radioactive decay the descent rate can be found near $8\% \cdot year^{-1}$. It was explained by the vertical deepening of ^{137}Cs in soil.

Another appropriate example of those processes can be found in [9], where the attenuation coefficient *R(T)* for the equivalent dose rate (EDR) from ^{134}Cs and ^{137}Cs due to deepening in soil is presented:

$$R(T) = 0.18 \cdot \exp(-1.4 \cdot T) + 0.65 \cdot \exp(-0.042 \cdot T), \ [T] = \text{year}. \qquad (1)$$

As it is seen from (1), the attenuation coefficient is described by sum of two exponents with half-life time values of 0.5 and 16.2 years. Several years after the Chornobyl accident the attenuation coefficient in expression (1) will be determined basically by the second member (i.e. 16.2 year). Such half-life time leads to the EDR descent rate of 4.1% a year. It can be noted that this descent rate corresponds more or less to the above-mentioned value for the Novozybkov area [8].

However, taking for calculation even the lowest EDR descent rate ($4.1\% \cdot year^{-1}$) for a period from 1997 to 2003, the total EDR drop would be quite a noticeable value of 22%. At the same time, for that period of time the EDR was measured in two points (Chornobyl and Benivka) by means of the automated system for monitoring of radiation situation (ASMRS) with frequency near 100 measurements a day. Those measurements showed surprisingly high stability. The point Benivka demonstrates even a certain increase of the EDR. Calculations were made taking into

account ^{137}Cs radioactive decay and EDR seasonal variations, connecting first of all with precipitations (rain, snow).

Thus, having analysed the gamma dose rate dynamics on the late stage of the Chornobyl accident it is possible to made a preliminary conclusion that the EDR does not confirm theoretical predictions of gamma dose rate decrease in 1997 – 2003.

Peroral intake of ^{137}Cs and ^{90}Sr

Internal exposure dose fluctuations for peroral intake is caused mainly by variation of "soil-diet" transfer factors (TF). It results in fairly wide dose distribution for the public. The reference annually averaged daily human diet according to [10] was used for average estimates of radioactivity intake to human organism.

"Soil-diet" TF distributions were modeled basing on data from [11-13]. As TF range for different diet components is very wide and makes two orders, it is assumed that TF for each component is distributed log-normally. Calculation of TFs for diet components of animal origin basing on data in [13] was carried out taking into account both transfer of radioniclide from soil into vegetable forage of animals and transfer of radioniclide from forage into animal. Also, culinary treatment of meal was taken into account. After all indicated terms the coverage factor was more than 10.

TF dynamics into vegetation and into human diet is an important factor for radiological forecast. As an example a bi-exponentional expression is used (according to formula 4.5 from [9]) as common factor f_m for all territories:

$$f_m(t)=0.9\cdot\exp(-t/4.2)+0.1\cdot\exp(-t/22),\ [t]=\text{year}. \qquad (2)$$

As it is seen from the formula, the second long-term component works predominantly more than 18 years after the accident: $f_m(18)=1.2\%+4.4\%$.

At the same time in [14] are presented ^{137}Cs TFs for natural herbage, potato, berries, meat, milk etc. Those TF data relate to Khanty-Mansi Autonomous District (KhMAD, Russia), where the Chornobyl fallout is negligible: local ^{137}Cs contamination is mostly formed by the global fallout resulted by nuclear weapon tests in 1950-60. It is important to note that soil types prevailed at KhMAD, are typical for Briansk region of Russia and for Pollissia (Ukraine). It is shown in that publication, TF is leveled off approximately 10 – 15 years after fallout and goes then stable. This important conclusion is confirmed almost by 30 years long observations for two important soil types: (1) sand and (clay) loam soil, and (2) black earth.

Comparison of the ^{137}Cs TF dynamics for the "old" (10-15 years) fallout taken from [9] and [14] demonstrates a substantial difference. While the dynamics in [9] gives slope of TF decrease in 4.4% a year, the dynamics in [14] does not show in general any slope at all for 30 years. (If hypothetically the TF decrease would be applied, as it was suggested in [9], than the TF would drop by 3/4 for 30 years). This disagreement can be explained (as it is indicated in section 4.2.1 [9]) by using data on TFs into milk (in Rivne, Zhytomyr and Kyiv regions) for 1987-1996. Actually this time period is quite short to provide reliable analysis of the long-term TF component.

Inhalation intake of TRU due to technogenic re-suspension

Dose forming properties of two scenarios: natural and technogenic ones of TRU re-suspension are considered and numerically compared in this section.

The first basic difference is in the concentration of suspended materials in atmosphere. A typical "background" mass aerosol concentration (about 50 $\mu g\cdot m^{-3}$) is used for the first scenario [15]. The mass aerosol concentration (about 500 $mg\cdot m^{-3}$) is used as the extreme dust concentration in air. Such high dust load (4 orders higher than "background" concentration) can be observed some time during building or agricultural works. Taking into account a typical mass of area unit of

upper soil layer, where "Chornobyl" radionuclides are mostly fixed, 100 kg·m^{-2} (that corresponds to 5-10 cm layer of soil), then the equivalent secondary (wind) re-suspension coefficient, will make 5.0E-10 and 5.0E-6 m^{-1}, accordingly for the first and second scenarios. The secondary re-suspension coefficient for the first scenario perfectly conforms the long-term experimental observation at the Chornobyl area.

Time of exposure is another difference between two scenarios: it is assigned 4000 and 650 hours accordingly to the first and the second scenarios. And finally the dose coefficient for TRU inhalation intake is the third difference: it is taken for the second scenario approximately 25% less than for the first scenario that represents the larger aerodynamic median by activity diameter AMAD in the second scenario.

Eventually the inhalation dose calculated for TRU soil contamination density (of 1 kBq·m^{-2}) makes 0.084 and 100 μSv·year^{-1}/(kBq·m^{-2}), accordingly for the first and second scenarios.

Table 1 - Dose forming factors for two scenarios: natural and technogenic TRU re-suspension

Factors and results of calculation	Re-suspension scenarios	
	Natural	Working atmosphere at intensive works
Aerosol mass concentration, mg·m^{-3}	0.05	500
Secondary re-suspension coefficient, m^{-1}	5.0E-10	5.0E-06
Average annual volume of breathing in conditions of the scenario, m^{3}·year^{-1}	4000	650
Dose coefficient for inhalation TRU intake, μSv·Bq^{-1}	42	31
Inhalation dose for the unit of the TRU soil contamination, μSv·year^{-1}/(kBq·m^{-2})	0.084	100

GENERALIZED CRITERION OF COMPLETE RELEASE FROM THE REGULATORY CONTROL USING THE SOIL RADIOACTIVE CONTAMINATION DENSITY AT THE CHORNOBYL EXCLUSION ZONE (INSTEAD OF CONCLUSIONS)

Calculation of a total conversion coefficient from the soil contamination density to the dose constraint is the end-points of the work. A total conversion coefficient is calculated using all the aforementioned factors, namely, TRU inhalation intake both for natural and technogenic re-suspension, ^{137}Cs and ^{90}Sr peroral intake via food chains and external exposure from ^{137}Cs as follows:

$$K = w \cdot e \cdot k_z, \qquad (3)$$

where e is the generalized conversion dose coefficient for the given factor, μSv·year^{-1}/(kBq·m^{-2}); k_z is the coverage factor, combined for some of factors with correction coefficients; w is weight coefficient, that actually represents contribution of the particular radionuclides into the total activity of "Chornobyl" mix at the late stage of the accident.

In Table 2 shows a structure of the total conversion coefficient from the radioactivity contamination of soil to the dose constraint for the Chornobyl Exclusion Zone. The coverage factor of TRU inhalation intake for natural re-suspension and external exposure from ^{137}Cs is taken straight from the above-mentioned materials for these factors. For cases of ^{137}Cs and ^{90}Sr peroral intake a combination of the coverage factor and the correction coefficient is applied approximately in equal parts ($10 \approx 3.2 \cdot 3.2$). TRU inhalation intake for technogenic re-

suspension scenario is assigned with the coverage factor 1 taking into account the sufficient conservativeness of the accepted scenario. Eventually the total conversion coefficient from the radioactivity contamination of soil to the dose constraint makes 12.9 μSv·year^{-1}/(kBq·m^{-2}).

The generalized criterion of complete release from the regulatory control using the soil radioactive contamination density at the Chornobyl exclusion zone can be defined as a ratio of two following values:

- the recommended by ICRP [17] level of complete release for post-accidental prolonged exposure for a critical group of the public, namely, 0.3 mSv·year^{-1} and
- the total conversion coefficient from the radioactivity contamination of soil to the dose constraint, namely, 12.9 μSv·year^{-1}/(kBq·m^{-2}).

Thus, the criterion of complete release from the regulatory control using the soil radioactive contamination density at Chornobyl Exclusion Zone makes 23.3 kBq·м$^{-2}$.

Table 2 - Calculation scheme for the total conversion coefficient from the radioactivity contamination of soil to the dose constraint for the Chornobyl Exclusion Zone

Exposure forming factor	Generalized conversion dose coef., e, μSv·year^{-1} /(kBq·m^{-2})	Coverage factor or correction coef. k_z	Conversion coef.. to dose constraint, $\hat{e}$ =e·k_z, μSv·year^{-1} /(kBq·m^{-2})	Weight coef., w	$\hat{e}\cdot w$
TRU inhalation intake for natural re-suspension	0.084	10	0.84	0.01	0.008
Inhalation TRU intake for techno-genic re-suspension	100	1	100	0.01	1
^{137}Cs peroral intake	0.5	10	5	0.70	3.5
^{90}Sr peroral intake	2.3	10	23	0.30	6.9
External exposure from ^{137}Cs	0.7	3	2.1	0.70	1.5
Total conversion coefficient from the soil contamination density to the dose constraint, μSv·year^{-1}/(kBq·m^{-2})					12.9

For completion of the work carrying out additional calculations regarding more careful verification of the total scheme, including time dynamics is actually needed. It is also necessary to develop and introduce certified internationally acknowledged and nationally approved methods for monitoring the compliance of the contaminated sites with remediation criteria.

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