LONGTERM CHERNOBYL CONSEQUENCES, COUNTERMEASURES AND THEIR EFFECTIVENESS

Belyayev S.T., Demin V.F.

1. INTRODUCTION

At least three stages are marked out in the post-accident activity : initial (several weeks), intermediate (several monthes) and long-term (years). The last one began in 1987. The year 1991 could be considered as a beginning of a new phase. In this year a new document "Concept of population living in regions having suffered from the Chernobyl accident" has been finalized.

On the basis of this concept, All-Union and Republican laws on the Chernobyl accident and the united long-term state All-Union and Republican program on population protection from the Chernobyl accident (for 1991-1995 and until year 2000) are being developed. These documents will regulate all practical activity directed on the elimination of the accident consequences.

The Concept has been developed by a working group, chaired by academician S.T. Belyayev, with participation of specialists from different All-Union and Republican organisations.

Issues of the accident consequences and countermeasures are considered in connection with development of the Concept. Available information is analized, which is important for this consideration.

2. ANALYSIS OF THE PRESENT SITUATION

2.1. Radiation situation

At present 137 Cs is the main dose forming radionuclide outside the 30-km zone. The area contaminated by 137 Cs above 5 Ci/km^2 is of about 28 000 km^2 with a population at the end of 1989 of about 800 000 people in more than 2000 villages and population centers.

The area with the level δ of contamination above 15 Ci/km^2 plus some adjoining settlements is called "a strict control zone" (SCZ). At the end of 1989, 273 000 people, in 786 settlements, lived in this zone. More details on radiation situation are presented in Table 1 and 2.

During 1990-1991 considerable efforts were applied on detailed measurements of radioactive contamination levels at all farms in the regions with 137 Cs concentration above 5 Ci/km^2.

The change of radiation situation is occuring due to :
- physical decay of radionuclides ($T_{1/2}$ (137 Cs) = 30 years) ;
- geophysical process of vertical transportation of radionuclides in deeper layers of soil.

The second process provides for faster decrease of radiation level above the earth surface. During previous years this decrease occured with period $T_{1/2}$ (geophysical) = 2-4 years. In future this decrease is expected to be progressively slower. However, credible prediction for time dependance of this process is not available. Different authors estimate this future time dependance in the range of $T_{1/2}$ = 7-14 years. The upper limit (14 years) is taken from studies of global fallouts. It seems reasonable that prognostic estimation of external dose should be based on this value, though it might be rather conservative.

According to available date the horizontal transfer processes (by wind, rain and high water) do not play any significant role.

2.2. Population doses

The population doses depend on :
- radioactive contamination of the environment,
- natural "decontamination" processes,
- contermeasures adopted.

Enormous data base on measurements and assessement of population doses is accumulated. Available dose assessment methods are being improved and adapted to the conditions of the Chernobyl accident. There are many publications on the subject, for example, in references [1-3]. Analysis of all information on this subject shows the following :

1. Countermeasures considerably decreased population doses. However these countermeasures were not performed in time in all cases and in full scope.

Mainly this remark is related to urgent measures in the first week after the accident directed to protect from radioactive iodine exposure. As a result ten thousand people received thyroid doses over 0.3 Sv and a considerable part of them, mainly children over 2 Sv. Relatively high doses were incurred by some participants in the elimination of the accident consequences.

2. Coutermeasure decision making is very sensitive to dose evaluation, taking into account different intervention levels in different time periods after the accident. It puts certain requirements on their accuracy.

Dose assessment methods available at the time of the accident could not provide, in some important cases, sufficient accuracy. As a rule, some conservatism principle wat put in these methods. This means that improvement of dose assessment methods is very actual.

3. Reliable date on internal (H^{in}) and external (H^{ex}) doses incurred in 1986-1989 may be received only on the basis of direct radiometric measurements. Due to the enormous accident scale, lack of sufficient number of measurement technique, and some organizational difficulties it was not possible to make measurements in necessary full volume. Part of the measurements turned out to be not sufficiently reliable.

At present certain work is carried out on improvement of previously incurred doses data on the basis of the measurement results, local condition studies and improved models.

4. As a rule the main part of the affected regions is in "nonchernozem" agricultural area. For these "nonchernozem" soils, the coefficients for cesium migration through food-chains and accordingly for internal exposure doses are relatively high. Without countermeasures (H^{in}) 2-3 times higher than (H^{ex}). This particular feature of local condition determines the importance of countermeasures directed to reduciton of (H^{in}).

5. *Doses during 1986-1989 years.* According to available data, the population in the strict control during 1986-1989 received average whole body dose H_b = 35 mSv (H^{ex}_b = 27, H^{in}_b = 8 mSv) [2]. For 96 % of the population, values of (H^{ex}_b) and of (H_b) do not exceed 70 and 100 mSv respectively.

6. *Doses during 1990.* Average external exposure doses H^{ex}_b during this year may be calculated from the following relationship :
H^{ex}_b = 0.1 mSv and 0.06 mSv per 1 Curie of 137 Cs per km^2,
respectively for rural and urban population. Internal exposure with account of adopted countermeasures which provide not exceeding control contamination levels for food products may be estimated as $H^{in}_b < 1$ mSv per year. This value depends weakly on level of radioactive contamination of the area.

Note, that in the Gomel region in 1989 in areas with > 5 Ci (137 Cs)/km^2 the value of (H^{in}_b) is estimated as equal to (0.4 mSv and 1 mSv) for urban and rural population respectively. Maximum values for (H^{ex}_b) and (H_b^{in}) (corresponding to 90 % percentage) exceeds corresponding average values by about 1.5 – 1.7 times. According to available estimates the adopted countermeasures decreased the (H^{in}_b) by about 10 times.

As a result, any person living near the border of the zone with 40 Ci 137 Cs/km^2 could receive in 1990 in average about H_b = 3 and 5 mSv for urban and rural areas respectively. The main part of this dose (about 75 %) is due to external exposure.

In absence of countermeasures H_b could exceed the above data by about 3-4 times.

7. *Future doses.* The precise prognosis of future doses is practically impossible. One could only give an upper estimate of (H_b^{ex}) and (H_b^{in}) on the basis of conservative assumptions on :
– future time dependance of γ – radiation exposure and of concentration in the soil of biologically accessible 137 Cs ;
– future countermeasures.

From these assumptions it is possible to estimate that in the area with 40 Ci/km^2 integral value for H_b^{ex} will be equal to 80 mSv and 50 mSv for rural and urban population respectively. For the whole SCZ one can make the following estimate :

$$(H_b^{in}) = \begin{cases} \leq 0.2 \text{ Sv without countermeasures} \\ 0.01 - 0.03 \text{ Sv under long keeping countermeasures.} \end{cases}$$

2.3. Socio-psychological situation.

In addition to radiation and other risk factors a socio-psychological factor acquired a considerable importance (stress, fear, agitation, which constitute the post-accident syndrome inherent to any extreme situation).

In the case of the Chernobyl accident it was strengthened by non complete and destorted information on the real situation as well as by nonadequate decisions on counter-measures or by their not timely execution.

This factor is revealed in the relocated population groups as well as in the population groups who continue to live in the contaminated areas.

There are reasons to believe that this factor became in many cases the prevailing one.

2.4. Public health.

Profound medical check-ups of the population living in the contaminated territories were conducted by the local health protection authorities and by the specialists of the leading national research institutes. Haematologists, endocrinologists, urologists and others were employed in the process of general clinic examinations.

Before 1986 no such population examinations were carried out.

The general clinic examination of the population in the contaminated regions has revealed an increased (as compared with 1986) number of various diseases and disorders in the normal health condition such as :
- diseases of organs of blood circulation and respiratory systems and other internal organs ;
- nervous diseases ;
- malignant tumours,

etc.

In other words, an increase is observed in the number of nearly all diseases which are known to the medical personnel in the contaminated regions.

Any dependance of the growth of the number of diseases on the radiation dose incurred by the population is not found, as a rule. The above mentioned diseases, with exception of leukaemias and malignant tumors (the latters have, as known, a prolonged latent period), have never been observed by the specialists studying the consequences of acute and chronic exposure of people.

The possible causes of the recorded growth of diseases :

methodical
- essentially improved screening of the population enabling the diseases to be sooner detected ;
- ignoring possible demographic changes ;

actual
- change in the tenor of life and habitual diet ;
- psycological stresses and anxiety resulting in physical symptoms and affecting health ;
- radiation exposure effects.

The latest factor could manifest itself in such a short time only as more frequent leukaemias, which is difficult to observe statistically.

A great work should be done in order to increase the confidence and reliability of the data on human disease rate at present and in the future.
Some averaged data characterizing the population health are presented in Tab. 3-5.

2.5. Countermeasures

Complex of the countermeasures realized includes :
- relocation,
- decontamination,
- agricultural measures,
- radiation control and monitoring,
- restrictions in life, work and recreation style,
- social and economic measures.

The most important countermeasures adopted earlier were urgent evacuation of 116 000 people in 1986 from the 30-km zone and relocation in 1990 of several tens of thousands people from areas with a contamination level above 40 Ci (137 Cs)/km² and partly from areas with lower contamination.

This relocation was carried out in accordance with "All-Union and Republican State Programme for Urgent Measures for Eliminating the Consequences of the Chernobyl Accident for 1990-1992" and will continue in 1991-1992.

Data on effectiveness of the countermeasures adopted have been accumulated.

On the basis of the evaluation of these countermeasures it is possible to conclude the following :

1. Some data on coutermeasures effectiveness related to the dose reduction were described earlier in this paper. Relocation may eliminate practically all future dose commitment. There is a real possibility to decrease internal doses on one order of magnitude. The main role being played by agricultural measures including when required clean food supply.

2. Apart from relocation there are some rather limited possibilities to decrease external doses (desactivation, limitations for style of living, work and recreation). The total desactivation does not provide considerable results. It is effective only for the most contaminated areas (separate spots etc.).

Limitations are not attractive from the socio-psychological point of view.

3. Countermeasures consideration on the basis of cost effectiveness or cost-benefit analyses leads to the following conclusions :
- relocation is not effective almost in all cases. It could only be justified by another principle of health protection (non-exceeding acceptable risk),
- in real conditions of regions affected by the Chernobyl accident, several specific agricultural measures, as a rule, proved to be effective ; desactivation is effective only in exceptional cases.

3. MAIN PROPOSITIONS OF THE CONCEPT

1. Apart from mandatory relocations forseen in the State plan for 1990-1992 any further obligatory mass relocations would not be justified. For populations living in the affected areas normal life conditions can be ensured (by carring out countermeasures where necessary). Possible additional relocations can only be voluntary.

2. The important feature of the Concept is including into the consideration.
- socio-psychological situations in affected areas,

– non-radiation risk factors,
– possible negative health effects from relocation.

The last effects can be caused by difficulties in adaptation of people to new living conditions in :
– socio-economic and industrial sphere ;
– nature environment including its bio-geo-chemical features ;
– non-Chernobyl anthropogenic contamination of the environment.

In the Chernobyl data there are only some facts in this topic, which are not valid for general conclusions. At present, data on other relocations and migration processes previously occured in the USSR are collected and analysed.

3. Accordingly the countermeasures considered include :
– improvements in medical service, directed on decreasing morbility and mortality both from radiation and non-radiation factors of risk ;
– measures on decreasing socio-psychological stresses.

The improvement in medical service directed to decrease the main risk factors (diseases of the blood circulatory system, "natural" malignant tumors, etc.) can be, especially in the USSR conditions, very effective. Even a small decrease of these factors could overcome considerably all possible Chernobyl effects (see Tables 3-5).

4. The strategy of population protection is determined by intervention levels. At least two such dose level should be implemented : lower and upper (see Fig. 1).

The low level is called "non-action level". Below, no countermeasures are required.

The upper level determines the limit for acceptable risk : if it is exceeded then relocation is necessary. In addition intermediate intervention levels could be introduced, which regulate decision making on countermeasures in the range between two main levels.

Option of dose indices and their values depends on a concrete situation in particular on a post-accident stage. Such dose indices can be a lifetime dose or a dose incurred for some limited time interval (e.g. one year or several years).

5. For the specific situation considered (the Chernobyl post-accident activity since 1991) it is reasonable to use annual doses and to establish the value of lower level equal to 1 mSv.

6. After the countermeasures realized by 1991 and natural "decontamination" processes the upper level (mandatory relocation) is not reached. Because of this, in the Concept, the problem of qualitative and quantitative definition of the upper intervention level is not considered. Here it should be noted that for the upper level value 0.35 Sv per life was established in the previous Soviet Concept (1988) [4] and 0.3.-0.5 Sv for months-years - in the international document [5].

7. The real Chernobyl situation since 1991 raised a conceptually and practically important issue about the previously incurred doses : how to take them into account in the decision making on countermeasures.

The proposition of the Concept concerning this issue is the following : Relocation can save only future doses. The previously incurred doses should be considered in "safe living" countermeasures but not in the decision making on relocation.

8. In the Concept the intermediate control level is established : annual dose of 5 mSv beginning in 1991 with recommendation to decrease it gradually in the future. This level should not be exceeded when a decision is made on an optimal complex of "safe living" countermeasures. Among the last there are contradictory ones, e.g. removal of limitations on life and work conditions as a countermeasure against socio-psychological stresses and radiation protection measures.

4. CONSEQUENCES

Consequences of the Chernobyl accident are determined by initial radioactive contamination of the environment, natural self-decontamination processes in biosphere, countermeasures and local conditions (see Fig. 2).
It is reasonable to divide consequences in two parts :
- those consequences which are already realized,
- futures consequences.

The first part can be estimated more or less reliably. Nevertheless, it contains some uncertainties, e.g. in value of earlier incurred doses.

In assessment of future consequences there are considerable uncertainties. This was stipulated by impossibility to give at present precise prognosis for :
- natural decontamination process,
- changes in future countermeasures.

Both processes will be corrected after reception of new data. As for the first process, its rate outside the 30 km-zone is at least twice as fast as physical decay of 137 Cs. (Some estimates for the Chernobyl accident consequences are given in Table 6).

5. CONCLUSION

1. In the strategy of the Chernobyl post-accident activity (establishment of intervention levels, choice of countermeasures, etc.) one should take into account besides radiation exposure :
- socio-psychological factor ;
- non-radiological risk factors ;
- negative health effects caused by relocation.

This reflects the real Chernobyl situation and expands possibilities in the choice of the most effective countermeasures complex.

2. Studying data on negative health effects caused by Chernobyl and non-Chernobyl relocation and migration of population in the past is of considerable importance, both for planning the Chernobyl long-term activity and for other possible accidental situations.

3. During the last years, the prolonged reconsideration of radiation risk coefficients (RRC) has been done. It has created some difficulties for decision making in radiation protection during the Chernobyl post-accident activity.

At the end of 1990, ICRP adopted recommendations on revised RRC which are considerably greater than the previous ones. Apparently in these recommendations, a conservatism principle was also used. It limitates using these new RRC in evaluation of radiological health effects, optimization of radiation protection, etc.

In connection with this point, an issue on establishment of "non-conservative" RRC as well as improvement of the effective dose concept, keeps its actuality.

4. Scientific data and recommendations derived from the Chernobyl studies are of considerable importance also beyond the Chernobyl post-accident activity.

REFERENCES

1. Ilyn L.A., Balanov M.I., Buldakov L.A. : Radiocontamination patterns and possible health consequences of the accident at the Chernobyl nuclear power station, Meditsinskaya radiologiya, No. 11, 1988, p. 59 (in Russian).
2. Barhudarov R.M., Buldakov L.A., Gordeev K.I. : Population doses in the controlled areas for 4 years after the Chernobyl accident.
3. Proceedings of an Intern. seminar on comparative assessment of the environmental impact of radionuclides released during three major nuclear accidents : Kyshtym, Windscale, Chernobyl, Luxembourg, 1-5 october 1990, CEC, 1991.
4. Concept of population health protection (35 rem concept), USSR NCR, USSR Population Health Ministry, No. 129-6/715-6, 1988.
5. Protection of the population in the event of a nuclear accident, NEA, OCDE, Paris, 1990.
6. USSR population, statistic annual report, Finansy i Statistika, M., 1989 (in Russian).
7. World population annual report, WHO, 1989.

Table 1

Areas S with different levels of contamination by 137 Cs

Interval of contamination, Ci/km²	S, 10^3 km²			
	BSSR	UkSSR	RSFSR	Total
5 - 15	10.2	2.0	5.8	18
15 - 40	4.2	0.8	2.1	7.1
≥ 40	2.2	0.6	0.3	3.1
≥ 15	6.4	1.4	2.4	10.2
≥ 5	16.6	3.4	8.2	28.2

(*) Including territories, from which population was evacuated.

Table 2

Number n_s of settlements and population N on the territories with different levels of contamination by 137 Cs (at the end of 1989)

Interval of contamination Ci/km²	N, 10^3 persons / n_s			
	BSSR	UkSSR	RSFSR	Total
5 - 15	267 / 836	204 / 202	113.1 / 425	584.1 / 1463
15 - 40	105 / 323	29.7 / 56	80.9 / 188	215.6 / 567
≥ 40	9.4 / 61	19.2 / 23	4.6 / 23	33.2 / 107
≥ 15	114.4 / 384	48.9 / 79	85.5 / 211	248.8 / 674
≥ 5	381.4 / 1220	252.9 / 281	198.6 / 636	832.9 / 2137

Average annual fatal risk from different causes in 1988 (10^{-2}/year) [6]

Causes of death	BSSR		UkSSR		RSFSR	
	M	F	M	F	M	F
Deseases of circulatory system	0.51	0.68	0.57	0.84	0.48	0.72
Malignant neoplasms	0.20	0.13	0.23	0.16	0.22	0.16
Accidents and adverse effects	0.14	0.04	0.14	0.04	0.18	0.05
Other causes	0.14	0.04	0.14	0.04	0.18	0.05
All causes	1.03	0.99	1.16	1.18	1.07	1.07
Malignant neoplasms from lifetime dose:	from the Chernobyl accident (*)					
305 mSv	< 0.024		< 0.024		< 0.024	
100 mSv	< 0.007		< 0.007		< 0.007	

Note:

M – male; F – female

(*) averaged on sex and time for 1986-2056.

Table 4

Lifetime risk R and life lost ΔT (in years) from some causes of death in BSSR, UkSSR and RSFSR

Causes of death	BSSR		UkSSR		RSFSR	
	R	ΔT	R	ΔT	R	ΔT
Deseases of circulatory system	0.61	7.5	0.63	8.4	0.60	8.2
Malignant neoplasms	0.15	2.3	0.16	2.5	0.16	2.5
Accidents and adverse effects	0.06	1.7	0.06	1.9	0.08	2.4
Other causes	0.18	1.3	0.15	1.4	0.16	1.5
	from the Chernobyl accident					
Malignant neoplasms from lifetime dose:						
305 mSv	0.02	0.44	0.02	0.44	0.02	0.44
100 mSv	0.005	0.12	0.005	0.12	0.005	0.12

Note:

R and ΔT were calculated using data from [6] and revised by ICRP radiation risk coefficients (conservative estimation for Chernobyl accident).

Age-sex-specific death rates per 100.000 people USSR, France, 1987 [6, 7]

Age Years	Sex	USSR	RSFSR	UkSSR	BSSR	FRANCE
Causes of death : deseases of circulatory system						
25–34	M	31.9	33.6	28.4	35.1	11.2
	F	12.2	10.0	10.1	10.5	5.3
35–44	M	135.9	143.1	123.5	151.9	41.0
	F	39.0	35.6	36.2	39.1	11.3
45–54	M	417.1	445.3	380.5	433.9	128.6
	F	146.2	141.7	136.5	142.7	93.5
55–64	M	1128.5	1193.0	1071.8	1047.9	372.1
	F	545.5	541.0	549.2	525.0	113.1
65–74	M	3177.4	3304.4	3193.4	3069.0	1029.2
	F	2012.1	1196.4	2109.0	1939.9	456.2
Cause of death : malignant neoplasms						
25–34	M	17.8	17.2	19.9	17.8	13.8
	F	19.4	19.3	22.0	18.7	11.2
35–44	M	71.8	73.9	80.4	75.3	56.9
	F	60.3	59.6	63.9	60.0	43.1
45–54	M	287.7	312.7	302.4	304.1	255.8
	F	153.7	155.9	159.0	144.1	127.5
55–64	M	769.5	841.6	755.2	702.9	673.1
	F	324.9	334.1	321.6	308.4	266.2
65–74	M	1269.6	1409.0	1196.4	1072.9	1235.3
	F	547.1	582.3	514.2	497.2	494.1

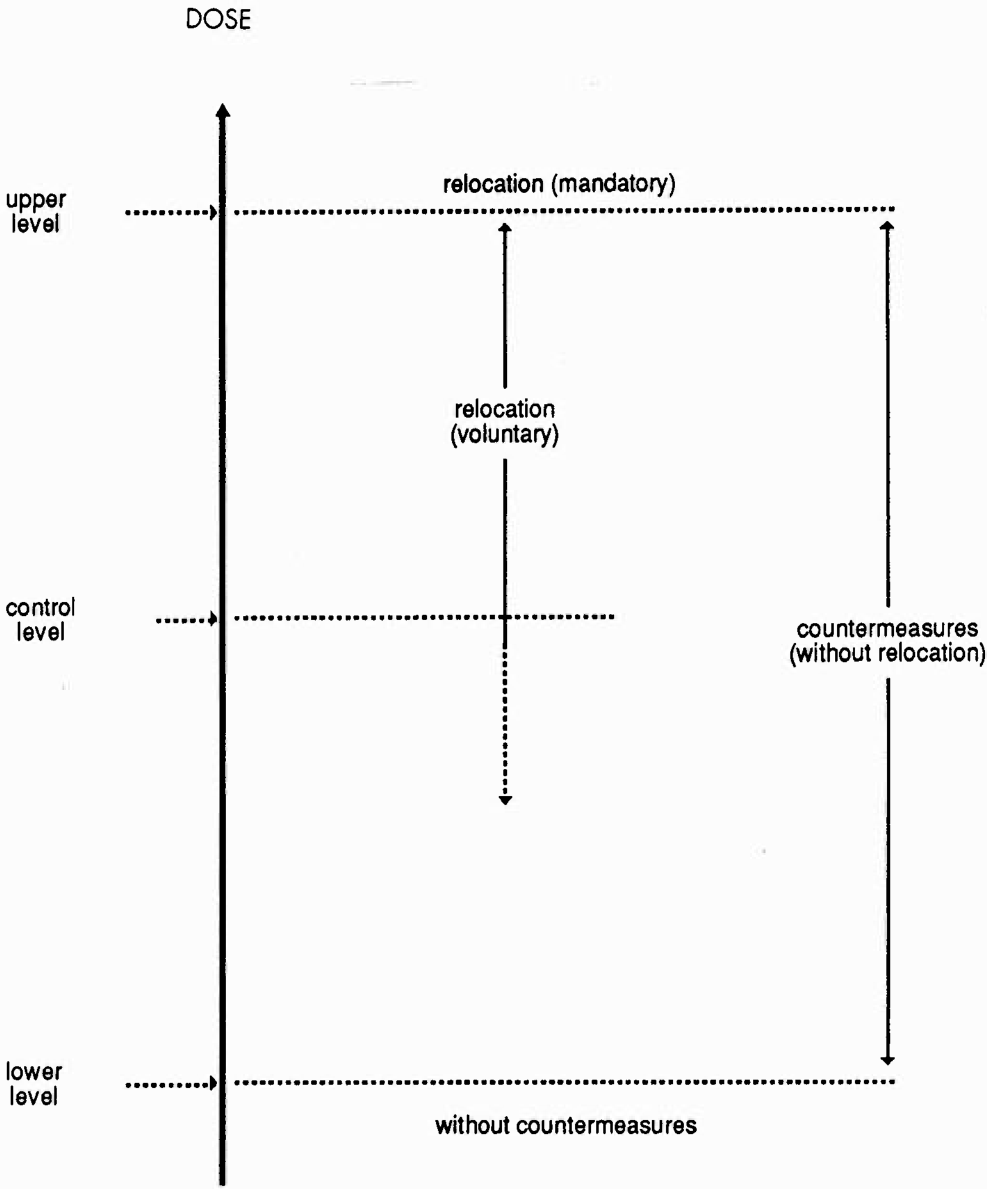

Fig. 1: SYSTEM OF INTERVENTION LEVELS REGULATING A STRATEGY OF COUNTERMEASURES.

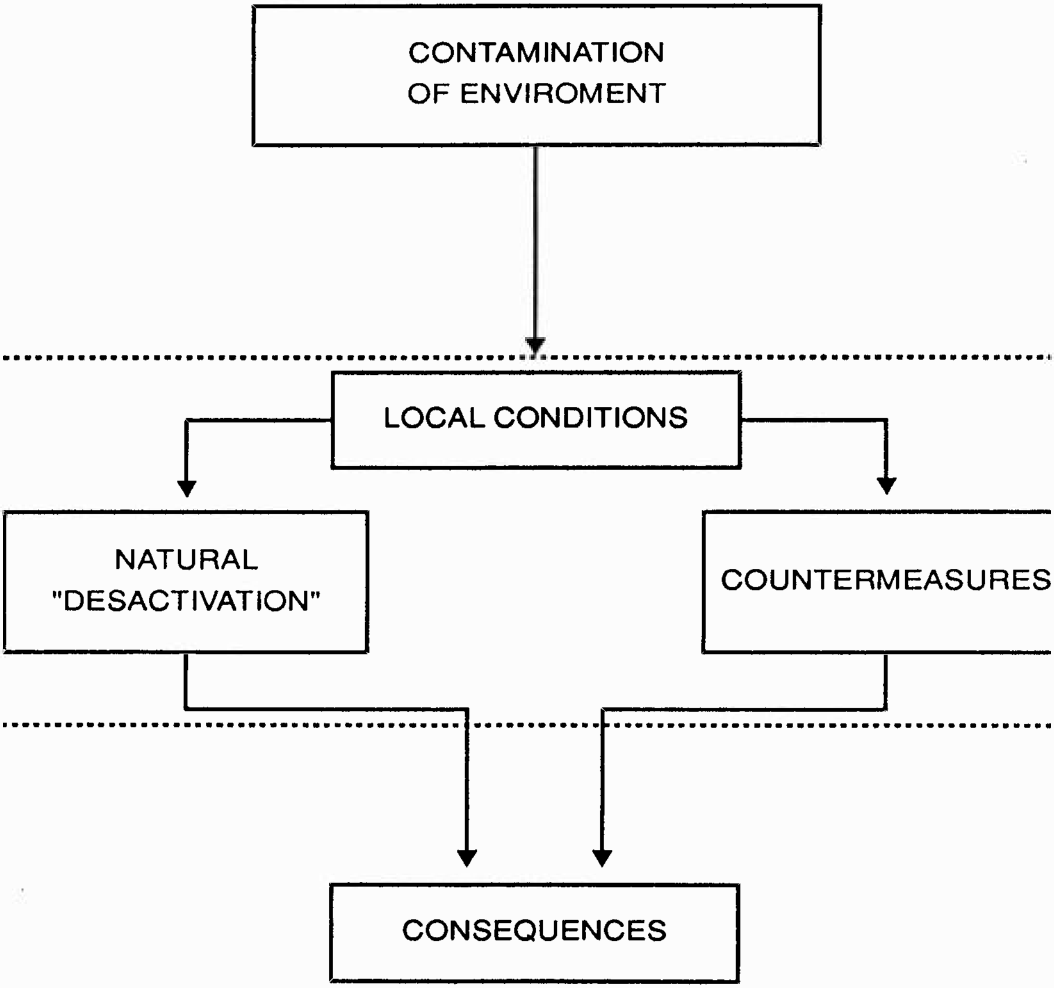

Fig. 2: FACTORS AFFECTING ACCIDENT CONSEQUENCES.