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Intervention criteria in CIS, risk assessments and non-radiological factors in decision-making. EU-CIS joint study project 2

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Risø-R-831(EN)

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Abstract An extensive radiation risk estimation methodology has recently been developed in Russia and used for estimates of risk in exposed populations in the republics of Russia, Belarus and Ukraine. Results based on demographic data for the three republics are presented and compared with risk estimates from the EU risk model ASQRAD.

The intervention criteria in the CIS republics have been evolving since the Chernobyl accident. The development of criteria in each of the three republics has been analyzed and the CIS-criteria have been compared to international guidance on intervention.

After a nuclear or radiological emergency both radiological and non-radiological protection factors will influence the level of protective actions being introduced. The role of non-radiological protection factors in the overall optimization of health protection is addressed. It is argued that optimization of the overall health protection is not a question of developing radiation protection philosophy to fully include socio-psychological factors. It is rather a question of including these factors - in parallel with the radiological protection factors - in cooperation between radiation protection experts and psychological specialists under the responsibility of the decision maker.

This work has been performed as a part of the EU/CIS Joint Study Project 2, "Development and Application of Techniques to Assist in the Establishment of Intervention Levels for the Introduction of Countermeasures in the Event of an Accident".

The open bridges in St. Petersburg.

ISBN 87-550-2085-2
ISSN 0106-2840

Print: Pitney Bowes Management Services Danmark A/S, 2008

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Foreword

The Chernobyl Centre for International Research (CHECIR) has been established by the former Soviet Union "for the purpose of conducting research programmes to be concluded on a bilateral or multilateral basis in the area of nuclear safety". The EU-CIS bilateral research projects within the CHECIR programme for 1995 cover several *Experimental Co-operative Projects (ECPs)* and *Joint Study Projects (JSPs).*

The Joint Study Project 2 (JSP 2) has been subdivided in 1995 into the following tasks:

- investigation of social and psychological factors,
- indirect countermeasures,
- interactions between countermeasures, socio-psychological factors and doses, and
- conceptual basis for developing criteria for setting intervention levels.

In the fourth project year the work on conceptual basis for developing intervention criteria has concentrated on the following subjects:

- radiation risk assessment methodology developed in CIS,
- comparison between CIS and EU radiation risk assessments,
- analysis of intervention concepts in CIS in the period 1983-1995, and
- evaluation of the role of non-radiological protection factors in the optimization of overall health protection.

This report describes the work performed during the fourth and final year carried out by the CIS-partners from the Ukrainian Research Centre for Radiation Medicine in Kiev, Ukraine, the Chernobyl State Committee in Minsk, Belarus, the Institute of Radiation Hygiene in St. Petersburg, Russia, the Russian Research Centre "Kurchatov Institute" in Moscow, Russia, and the EU-partners from CEPN in Paris, France and Risø National Laboratory in Roskilde, Denmark.

1 Introduction

In the event of a nuclear accident or radiological emergency resulting in the dispersion of radioactive materials into the environment, the effective implementation of measures for protection of the public will largely be dependent upon the adequacy of *advance preparation*, including the preparation of an *emergency response plan* to control and limit the consequences of the accident. Important parts of the plan will be emergency procedures including intervention and action levels for protective measures and instrumentation and manpower requirements for accident assessment, protective measures and communication.

Radiological emergency assessment and response require an interdisciplinary approach. The procedures leading to decision making must ensure that all due weight and consideration are given to each specialized aspect of the wide ranging problems following a nuclear accident or radiological emergency. At each major decision point, the decision maker must consider the facts as they have been determined at the time. Having determined, from dose projections for individuals, that protective actions are needed, the decision maker must then consider the risks and social costs associated with implementing a protective measure.

The decision maker will have to contend with economic and political constraints on the resources with which to implement the recovery plans and on the acceptability and credibility of priorities and criteria for recovery. The recommendations of specialized advisers are also 'decisions' in the sense that they represent assessment of what the situation call for, albeit from specialized or limited viewpoint. However, many constraints and competing 'decisions' will have to be weighed and balanced to arrive at a final decision which leads to the best way to protect public health and safety and to assist the long term recovery process.

Some major deleterious impacts of a nuclear or radiological emergency cannot be quantified in terms of radiological dose although they may be regarded as components of the detriment related to the accident. They are effects such as anxiety about the situation in general or about the threat of radiation exposure (generally related to the risk perceived), together with discomfort or inconvenience caused by protective measures. In decision making on protective measures there will be several objectives, of varying degree of importance. While the main objective, namely dose reduction, is the same during the earlier and later phases of an accident, competing requirements and constraints are likely to become much more prominent in the later stages.

Following the accident at Chernobyl, it became evident that some clarification of the basic principles for intervention was warranted. During the last decade, radiation protection criteria for protective measures following a nuclear accident have thus been developed by the international radiation protection organisations. This process has created a lot of confusion because intervention levels for introducing countermeasures have been interpreted as doses *received* and not as doses *averted* which wrongly has been interpreted as if intervention levels were dose limits.

The recent development of intervention principles by the IAEA [21], ICRP [29] and NEA [39] are based on the justification and optimisation principles, namely that each countermeasure should be justified, *i.e.*, do *more good than harm,* and the level of the protective measure should be optimised, *i.e.*, do *the most good.* Each countermeasure should be optimised *separately*, independent of other countermeasures.

Avertable doses from protective measures can be expressed in terms of avertable individual risks or avertable expected consequences, *eg*, avertable collective years of life lost, in the affected population. When countermeasures are not implemented because the avertable doses will be less than the intervention level or when countermeasures are lifted, the residual doses can similarly be expressed as lifetime risks from the residual lifetime exposure of the different age groups in the population. The residual individual risk of stochastic effects after protective measures have been taken is often a significant concern to national authorities. For decision-making on the introduction of countermeasures and social protection it is therefore necessary to assess both avertable and residual risks.

A radiation dose will involve a risk commitment, *i.e.*, a commitment of an increased cancer death probability rate in the future, after a latent period which may be from a few years in the case of leukaemia to tens of years for other malignant conditions. Any change in the age-specific death probability rate would therefore occur later in life, when the risk of death from their causes is also higher.

Individual risk considerations can be directly incorporated into the setting of intervention levels which could be expressed in avertable individual risk of radiation induced cancer. The basis for estimating individual risk levels is thus a very important issue in decision making following a nuclear accident.

A number of computerized systems for quantification of radiation risks have been developed on the basis of general risk assessment methodology and radiation risk models produced by international and national organisations. Examples on such systems developed within CIS and EU are BARD [5] and ASQRAD [2]. Their aim is to provide a flexible, easy-to-use tool to quantify somatic and hereditary risks due to both short-term and prolonged radiation exposure.

2 Risk Quantifications

2.1 Computer system BARD

Since 1994 in the framework of the Russian federal research programme, the international (EU - CIS) post-Chernobyl project JSP2 and partly the IAEA Coordinated Research Programme "Comparative Health and Environmental Risks of Nuclear and Other Energy Systems" the research project *developing the methodology (MAR) and data bank (BARD) on health risk analysis has been carried out* [12].

The main applications of BARD are:

- assessment of the radiological and non-radiological consequences of nuclear tests and accidents,
- assessment of radiation risk due to any source of exposure,
- health risk assessment and comparison for different energy production systems,
- assessment of the health of a population in terms of risk indices (indicators),
- analysis of effectiveness of health protection measures.

Besides BARD can also be used for other tasks related to risk analysis. BARD includes:

- service and calculation codes realizing the methodology mentioned,
- the intrinsic data base with the health-demographic data (HDD) for many regions and years which are necessary for radiation and non-radiation risks assessment.

HDD have been prepared for population of many regions of Russia for different years, for some regions of CIS and some countries around the world. The sources of these data are the health-demographic State Statistics of FUSSR and Russia, the health-demographic WHO statistics, etc.

The BARD data base contains the following HDD for any concrete population:

- age distribution density,
- age-cause-specific morbidity rates (under development),
- age-specific fertility rates (under development),
- age-cause-specific death rates.

The last HDD are given in two modifications:

- aggregated form,
- detailed form.

In the aggregated form all health risk causes are divided into 8 combined groups:

- infection and parasite diseases,
- malignant neoplasms,
- circulatory system diseases,
- respiratory system diseases,
- digestive system diseases,
- accidents and adverse effects,
- other diseases,
- all risk causes.

In the detailed form each aggregated group is sub-divided into more specific subgroups. Detailed subgroups for the malignant neoplasms include:

- leukaemia,
- respiratory cancer (lung, bronchus, ...),
- breast cancer,
- digestive cancer (stomach, colon, rectum, ...),
- others (liver, urinary tract, ...).

In CIS and Russia HDD are prepared for population of: a state, a region, a city, a settlement or some other specific cohorts.

Any array of HDD is additionally subdivided into subgroups:

- male, female, both sexes,
- urban, rural or total population.

The calculation codes have been prepared on the basis of methodology of risk assessment being developed in parallel with BARD.

In radiation risk assessment part of BARD the following models were implemented:

- UNSCEAR-94,
- BEIR V,
- UK NRPB.

Input data for BARD are divided in two parts:

- external (prepared and supplied from outside BARD),
- internal (taken from the intrinsic HDD data base and prepared inside BARD).

For a radiation risk assessment external input data are values of absorbed or equivalent doses (short-term exposure) and dose rates (extended exposure) of different human body organs due to radiation exposure from a source considered. These doses or (and) dose rates should be given in their dependence on age, time at exposure, countermeasures adopted etc.

For non-radiation risk assessment input data can be age-cause-specific death or disease rates or some variations of the background HDD prepared using the data from the internal data base.

Output data of BARD in accordance with MAR are values of different risk indices on cohort (individual) and population levels:

- lifetime risk (a probability of death or a disease from a risk source considered) during the whole future life or the respective risk rate,
- detriment to human health due to some death cause (defined as a loss of life expectancy in man-years) on the cohort (individual) or population levels,
- mortality or morbidity due to a risk cause in a some cohort with specific age and sex composition or in a total population considered during some limited time interval (*eg* 1 year) or remaining lifetime of that population.

All these risk indices are determined in MAR.

Risk indices calculated can be given in their possible dependence on age, sex, local conditions, time etc. or in an average form.

These forms of output data are specialized by a task for calculation and can be determined in input data or from a computer screen.

Dependence of the risk indices on any protective measures is determined through the input data (variations of doses, other risk causes characteristics due to these measures).

BARD is constantly supported and developed in the two versions (local and distributed, accessible through Internet) at RRC "Kurchatov Institute" (Moscow, Russia) with participation of other organizations. To the end of 1995 the data base of BARD includes HDD for more than 200 different cohorts in aggregate or detailed forms and in different years for:

- Total FUSSR,
- Belarus (few),
- Ukraine (few),
- Russia (many cohorts for the total state and different regions including those suffered from the Chernobyl accident),
- some other UN states (France, UK, USA, ...).

Some simple demonstrative distributed version of BARD can be already accessible through Internet (`http://nsi.net.kiae.su/`).

The BARD risk assessment methodology is described in details in Appendix A.

2.2 Computer system ASQRAD

The risk calculation program ASQRAD (**A**ssessment **S**ystem for the **Q**uantification of **RA**diation **D**etriment) is a Windows based tool for PCs. It has been jointly developed by the CEPN (Centre d'etude sur l'evaluation de la protection dans le domaine nucleaire) in France and the NRPB (National Radiological Protection Board) in the UK with support from the European Commission [2].

The aim of ASQRAD is to provide a common framework for applying measures of radiation detriment. The code has been designed to be a flexible, easy-to-use tool with the facility to quantify somatic and hereditary effects, based on a wide selection of health effect models for both individuals and populations. It contains a data base from a wide selection of countries, but it also allows the user to input alternative data and model parameters.

A range of somatic effects models is available within the program. These are the multiplicative and additive models proposed by the UNSCEAR (**U**nited **N**ations **S**cientific **C**ommittee on the **E**ffects of **A**tomic **R**adiation) in its 1988 [42] and 1994 [43] reports, the RERF (**R**adiation **E**ffects **R**esearch **F**oundation), the US BEIR V Committee [44] and by the NRPB in its 1993 report. A model developed by the ICRP (**I**nternational **C**ommission on **R**adiological **P**rotection) and detailed in its Publication 60 [28] is also included within ASQRAD to quantify the hereditary effects of an exposure to ionising radiation. The program allows the user to the parameter values of all these models.

ASQRAD is able to perform four main types of detriment calculation, based on different combinations of individual or population exposure and somatic or hereditary effects as shown in Table 1.

Table 1. Calculation mode with the ASQRAD model.

Calculations available	Exposure type	Exposure duration	Age at exposure (acute exposure only)
Individual Somatic	Whole body or Organ Specific	Acute or Extended	Single or Multiple
Population Somatic	Whole body or Organ Specific	Acute	n/a
Individual Hereditary	Gonads	Acute or Extended	Single or Multiple
Population Hereditary	Gonads	Acute	n/a

ASQRAD provides various measures of detriment depending on the type of calculation being performed.

For somatic effects the measures of detriment provided are the number of fatal cancers, the total cancer incidence and the average loss of life expectancy. In addition to these, a number of intermediate measures that are derived during the process obtaining the main measures are made available to the user.

For hereditary effects the main measure of detriment provided is the probability of an effects in the subsequent generations. The distribution of these effects over the first to the tenth generations is provided for each category of hereditary effects.

2.3 BARD risk calculations

Some results of health risk estimations have been made with BARD for the Bryansk region territories with relatively high ^{137}Cs-contamination from the Chernobyl accident (> 30 Ci·km^{-2}) in [19] (see also other results of BARD [1]). Here some additional results for the same territory of the Bryansk region are presented (Figs. 1 - 4).

The following input data were used for these estimations of the health risk with BARD:

- **h**ealth **d**emographic **d**ata, HDD (the age-cause-specific death rates and the age distribution density) for the rural population of the Bryansk region in

1989,

- results of dose assessment for selected territories available from the Russian Chernobyl research studies and the international EU-CIS Projects JSP2 and JSP5.

All the present calculations were made with the primary radiation risk models from BEIR V.

It should be emphasized that a considerable improvement in the Chernobyl dose assessment methodology and results have been made in the last few years (1993 - 1995). The improvements can be characterized as:

- the calculations take into account more realistically dose and dose rate dependence on time, local conditions and countermeasures,
- the calculated doses are considerably lower then the preliminary results of the estimations made up to 1991 and analyzed in the International Chernobyl project (1989-1991).

The following dose components are included in the risk assessment:

(a) short-term whole body dose during the first few weeks (equivalent dose H_0),

(b) thyroid dose (absorbed dose D_{th}),

(c) chronic whole body dose described by the equivalent dose rate $\dot{H}(t)$ with its external and internal parts and their respective time dependence.

For the population and territory chosen $H_0 = 50$ mSv (compared with 80 - 100 mSv from the estimations up to 1991), $D_{th} = 0.3$ Gy for adults with increasing doses towards lower ages as described in [30] (2 and 4 times higher for children with ages less than 18 and 7 years, respectively). Two variants of $\dot{H}(t)$ are used here for the risk estimation:

(1) $\dot{H}(t)$ without any countermeasures (the internal doses are higher than the external doses (1.5 times in 1990)),

(2) $\dot{H}(t)$, which have been observed and predicted taking into account the countermeasures adopted (the internal doses are considered lower than the external doses (3 times lower in 1990)).

A strong dependence of the individual life time risk, R, with age at time of the accident can be observed in Fig. 1 the value of R is relatively large for children and juveniles and decreases fastly towards older ages. This dependence is similar for all kinds of cancer except for respiratory cancer. For this type of cancer, the risk is highest at ages 35 - 40 years. Such behaviour of R is well known from the literature, *eg*, ICRP Publication 60 [28].

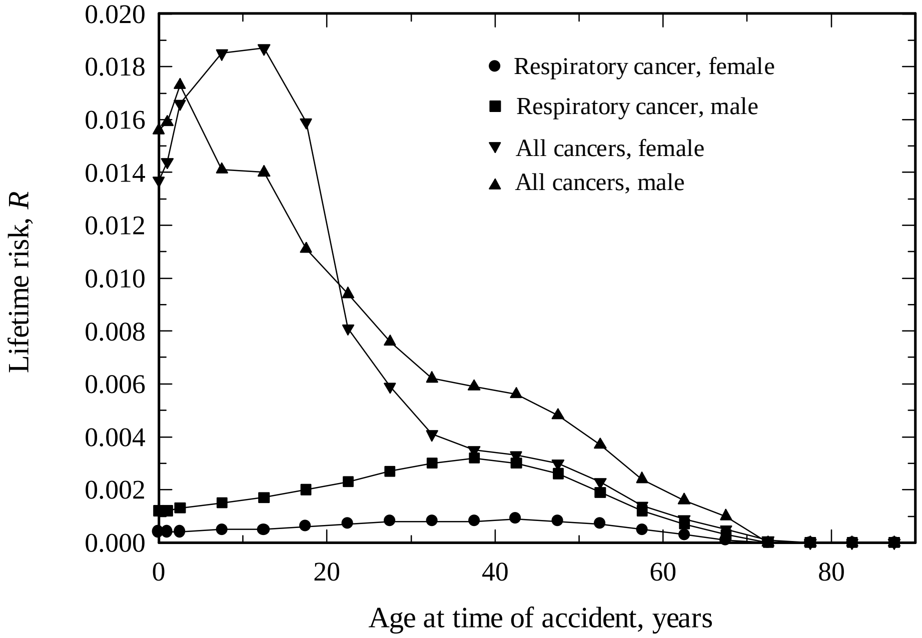

Figure 1. Life time risk R from lethal radiogenic cancers, as a function of age at the time of accident.

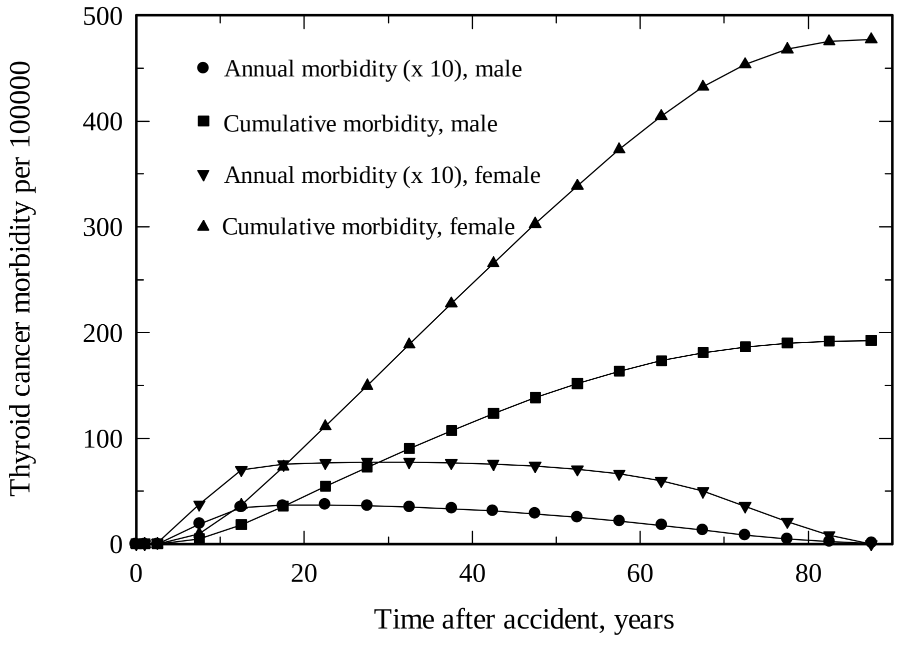

Figure 2. Excess morbidity from radiogenic thyroid cancers (due to the Chernobyl accident) per 100 000 persons at age 0 - 18 years at the time of accident, as a function of time, t, after the accident.

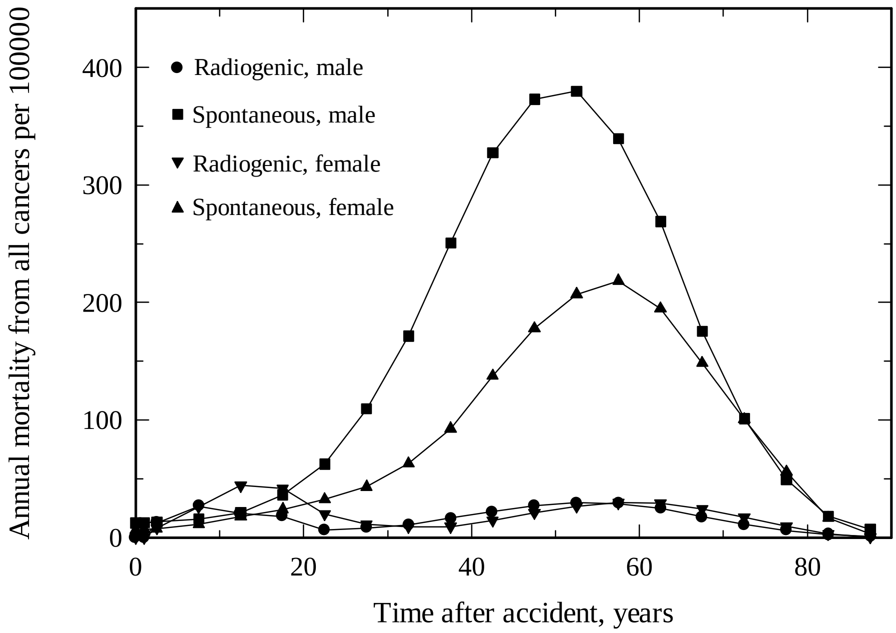

Figure 3. Annual mortality rate, $\dot{M}(t)$, from spontaneous and radiogenic cancers (due to the Chernobyl accident) per 100 000 persons at age 0 - 18 years at the time of accident as a function of time, t, after the accident.

The specific feature of Figs. 1 - 4 is that R and $\dot{M}(t)$ were calculated for the population of the Bryansk region with HDD as described above and for the mixed exposure due to the Chernobyl accident (acute plus extended). The age dependence of the radiation risk was taken into account when the above age groups for the risk calculations were chosen. The predicted excess cases of most of the radiation-induced cancers are rather low at any time after the accident, even without countermeasures (see Fig. 3 and [19]): less then ten percent of the mortality due to the respective spontaneous cancers. It is therefore not reasonable to plan any epidemiological study to observe these health effects from the Chernobyl accident.

However, the situation is different for radiogenic thyroid cancer and leukaemia. Values of $\dot{M}(t)$ for these types in the proper time intervals after the accident are relatively high and can in principle be observed in an epidemiological study. This is due to the relatively low occurrence of these spontaneous cancers and their relatively high radiation risk coefficients.

Many national and international studies are being carried out regarding the thyroid cancers following the Chernobyl accident. A few hundreds of excess thyroid cancer cases have already been observed in the regions of Belarus, Russia and Ukraine affected by the accident (see *eg* [30]). The risk assessment prediction for the excess thyroid cancers (see Fig. 2) is in a reasonable agreement with the results of the epidemiological studies in the Bryansk region. From 1987 to 1995 the total of 48 cases of thyroid cancer were observed (for people of age 0 - 17 years at the time of accident and with the male/female ratio close to 0.5) [19]. Few such spontaneous cases could be observed for the same cohort and time interval (BARD calculation based on the background HDD for the Bryansk region).

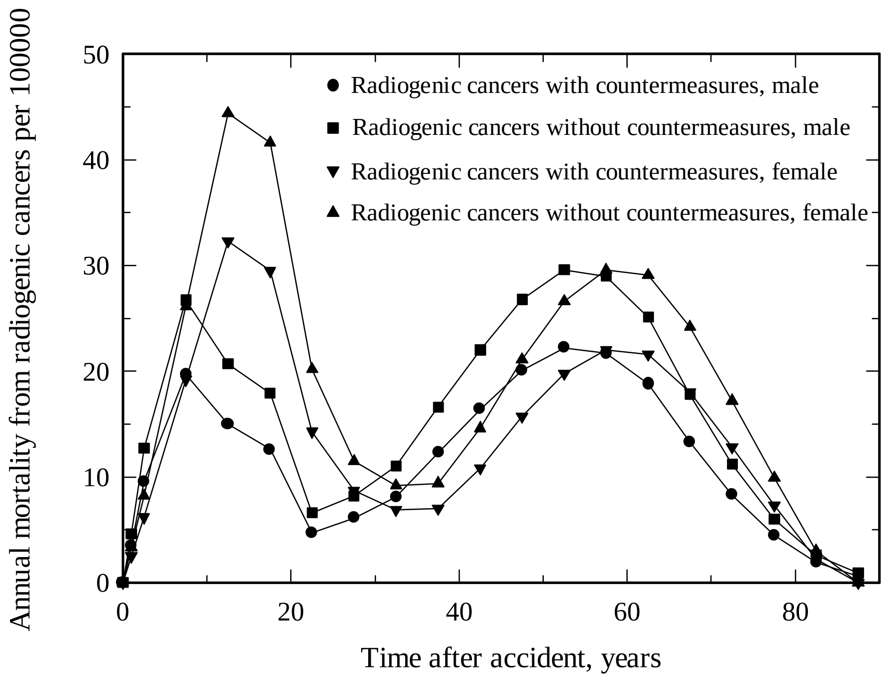

Figure 4. Annual excess mortality rate, $\dot{M}(t)$, from radiogenic cancers (due to the Chernobyl accident) per 100 000 persons at age 0 - 18 years at the time of accident as a function of time, t, after the accident with and without countermeasures.

Regarding the radiogenic leukaemia no statistically reliable excess cases were observed in studies up to 1994. The problem of the radiogenic leukaemia continues to be under investigation, both in the epidemiological studies and for risk assessments with radiation risk models available.

Peculiarities of excess health risk due to the radiogenic thyroid cancer, leukaemia and other cancers should be taken into account in preparing and performing the health protection and rehabilitation programme for the current and following years in the territories affected by the accident. The detailed risk assessment data can here be a good basis for decision making for this application. It should be emphasized that in Russia the additional development of regulatory documents for radioactively contaminated territories using the risk assessment results has already begun.

It follows from the results that the total radiological health risk caused by the Chernobyl accident is rather low (especially for the adult population) in comparison with the health risk from all spontaneous cancers even on the territories with relatively high levels of radioactive contamination.

In the late 1980's it was predicted that the socio-psychological factors can have a considerable negative health effects together with the radiation exposure itself due to the accident [3]. In the 1990's many results from studies of the population health effects in the territories affected by the accident supported the correctness of this prediction (*eg* [31]).

It is planned to estimate non-radiological health effects with BARD using the results of the socio-psychological studies carried out in the frame of Russian Federal Research Programme and the international EU-CIS Project JSP2. It is also planned to carry out sensitivity and uncertainty analyses to make the risk estimation results more complete and reliable.

The effect of the radiation protection countermeasures adopted expressed in terms of *avertable risk* (see Fig. 4) and effectiveness is as a rule rather low. It could be considerably increased if also non-radiological protection were to be included. Costs of the unit avertable risk (1 person·day lost) for the countermeasures adopted are no less then 30 rubles (much more in the most cases). Cost values of the proper medical health protection and rehabilitation measures are considerably or many times lower (the effectiveness is higher) in the specific condition of CIS. It is true even for the territories with the highest levels of radioactive contamination. Results of the study in this area are prepared for publication. Some preliminary results can be found in [4].

To demonstrate non-radiation risk assessments with BARD the results of estimation of lifetime risk, R, and loss of life expectancy, G, of the total population of France and Russia are shown in Tables 2 and 3.

Table 2. Lifetime risk R and loss of life expectancy G due to different background risk sources (France, 1987; calculation with BARD).

Risk source	G, man-years		R	
	male	female	male	female
Infection and par. diseases	0.1	0.2	0.01	0.01
Malignant neoplasms	5.2	3.6	0.31	0.21
Circulatory system diseases	5.3	7.5	0.33	0.41
Respiratory system diseases	0.7	0.6	0.07	0.05
Digestive system diseases	0.8	0.7	0.05	0.05
Accidents and adverse effects	2.1	1.2	0.08	0.07
Other diseases	2.8	3.3	0.15	0.20
Life expectancy, years	74.8	83.7	-	-

Table 3. Lifetime risk R and loss of life expectancy G due to different background risk sources (Russia, 1989; calculation with BARD).

Risk source	G, man-years		R	
	male	female	male	female
Infection and par. diseases	0.4	0.2	0.01	0.01
Malignant neoplasms	2.7	2.1	0.20	0.13
Circulatory system diseases	13.2	33.9	0.51	0.72
Respiratory system diseases	1.0	0.6	0.07	0.04
Digestive system diseases	0.3	0.3	0.03	0.02
Accidents and adverse effects	3.9	1.2	0.13	0.04
Other diseases	1.6	1.4	0.05	0.04
Life expectancy, years	65.3	75.3	-	-

2.4 Comparison between ASQRAD and BARD calculations

Both computer systems ASQRAD and BARD on their current stage of development are rather large and complicated. They content data bases and their management, calculation codes for all possible modes of radiation exposure and risk indices, management systems of preparing input and output data etc. ASQRAD and BARD need to be proved in all their parts, including first of all the calculation codes. It is obvious that the authors of the systems continually make such approval in the process of developing the systems.

Table 4. Values of radiation risk indices, R, and g = G/R (where G is the detriment index) for different cancer type (or localization) as a result of calculation with BARD/ASQRAD (single whole body exposure, D = 0.1 Sv, dose and dose rate reduction factor DDREF = 1, a is the age at exposure).

a, years	lung	breast	leukaemia	digestive	other
$R \cdot 100,000$					
male					
0	85/84		160/170	560/550	300/300
20	160/160		24/23	570/580	190/180
50	310/450		72/80	56/65	36/38
female					
0	23/23	58/58	95/100	620/650	350/370
20	40/43	39/37	19/18	630/670	220/220
50	77/100	5.6/5.6	42/46	64/76	33/38
g, years					
male					
0	16/16		54/55	14/14	15/15
20	16/17		31/30	14/14	13/14
50	11/12		12/13	9/10	9/10
female					
0	19/21	30/32	63/67	14/16	18/20
20	19/22	26/28	38/39	14/16	17/19
50	11/15	11/13	14/17	9/12	9/13

Table 5. Values of radiation risk indices, R and g = G/R (where G is the detriment index) for different cancer types (or localizations) as a result of calculation with BARD/ASQRAD (chronic whole body exposure, D = 0.001 Sv/year, dose and dose rate reduction factor DDREF = 1, a is the age at the beginning of exposure).

a, years	lung	breast	leukaemia	digestive	other
$R \cdot 100,000$					
male					
0	120/145		43/42	175/174	83/83
20	96/130		20/19	66/67	30/31
50	28/51		10/10	5/7	3/3
female					
0	32/42	24/24	32/30	200/210	100/101
20	26/37	6/6	14/14	75/82	34/37
50	9/16	0.3/0.4	5/6	6/10	3/4
g, years					
male					
0	14/14		32/33	13/14	13/14
20	13/14		15/15	13/13	12/12
50	9/10		10/10	8/8	8/8
female					
0	14/16	27/29	39/41	13/15	16/18
20	13/16	20/23	18/20	12/15	14/16
50	7/11	8/11	10/13	7/10	7/10

Since 1995 cross comparison of results of ASQRAD and BARD began. It can be considered as an additional test. At the same time this cross comparison has a specific importance for an official approval of the systems in cases of their practical applications. In this section some examples of such cross comparison are given. All calculations for this section were made using the HDD for rural population of Russia in 1989 (taken from the BARD data base) and the primary risk model from BEIR V.

Good or reasonable agreements between results from both computer systems for the variants considered are observed in Tables 4 and 5.

3 Intervention after a Nuclear or Radiological Emergency

The health consequences of a nuclear or radiological emergency include more than the increased risk of stochastic radiation effects attributable to the emergency. Different causes can lead to increases in psychological strain in the affected population, and there will be mental distress and anxiety associated with any accident, regardless of whether an actual radiation dose has been received or not. This is attributable to the perception of a risk to health, and depends in part on whether people have confidence that the authorities are competent and trustworthy and have taken prompt and effective action to control radiation doses.

3.1 Purpose of intervention

In the event of an accident, doses to individuals in the affected population can only be reduced by intervention, *i.e.*, through the imposition of protective measures, which will normally inconvenience people and alter their environment. These measures may include sheltering, evacuation, administration of stable iodine tablets, banning of contaminated food, modification of agricultural and industrial processes, decontamination measures, temporary relocation or permanent resettlement of the population.

Such measures are not without their own harmful effects: some have direct implications for health and well-being; they all require restrictions on people's freedom of action or choice; and resources may have to be diverted from other socially beneficial purposes to pay for them. Therefore, in selecting the level above which a given protective measure should be taken, a balance needs to be struck between the benefits of the measure, in terms of reducing the risk to health from radiation, and the harm from the measure itself.

When faced with a need for intervention, every possible effort should be made to prevent anyone receiving doses above the thresholds for serious deterministic effects. Indeed, because there will necessarily be uncertainties in the prediction of doses received, all doses should be kept somewhat below the threshold to ensure that no one suffers a serious deterministic health effect.

Stochastic effects typically include a wide range of cancers and hereditary effects, which may not occur until many years after the initial exposure. For a large population, all receiving small radiation doses, it is possible to estimate statistically the expected number of extra stochastic effects that would occur. However, since other causes not related to radiation can give rise to similar effects, it is impossible to distinguish with certainty which of the individuals suffering the effects do so as a direct result of the radiation exposure.

The health consequences of a nuclear accident would include those *not* related to radiation doses, *eg*, psychological strain and anxiety. Protective measures might thus be introduced to mitigate such consequences thereby improving the overall health conditions in the affected population. Such protective measures may have no influence on the radiological situation at all, or they might even result in an increase in doses. If, however, the reduction of non-radiological health impact is greater than the increase in radiological health impact, the measures would have a positive net benefit and thus be justified on an overall health ground.

The quantification of non-radiological health risks is not an easy task and the comparison and trade-off between radiological and non-radiological health consequences is, therefore, extremely difficult.

3.2 Radiological and non-radiological protection factors

The principles of justification/optimization of intervention each require consideration of the benefit that would be achieved by the intervention and the harm, in its broadest sense, that would also result from it. They therefore require the use of the procedures for reaching decisions. The inputs to justification and optimization studies include factors that are related to radiological protection, whereas the final decisions may also depend on other factors, probably of a political nature [24, 27].

3.2.1 Radiological protection factors

Radiological protection factors are defined as those which are related to the level of radiological protection achieved. Thus they include those factors describing the dose distribution averted and those describing the costs and other disadvantages incurred in averting the doses. All these techniques have as their primary objective to clarify, for the people who have to decide on the intervention, the various factors, to quantify them if this is reasonable and necessary, and to systematize the trade offs between the various factors.

Factors which would clearly be radiological protection factors are:

- the averted individual and collective risks for the members of the public,
- the individual and collective physical risks to the public caused by the countermeasure,
- the individual and collective risks to the workers in carrying out the countermeasure, and
- the monetary cost of the countermeasure.

The factors include those describing benefits from the countermeasure and those describing harm. In analyzing the inputs to the decision, it is necessary to decide on the *relative importance* of each factor. These judgements have to be applied *irrespective* of the decision aiding technique used. The resultant decision is the same provided that the database is the same and the judgements are consistent. If multiattribute utility analysis is the technique used, then all the radiological protection factors can be directly included in the analysis by deriving or assigning utility functions to them, and the tradeoff judgements are expressed as scaling constants. If cost-benefit analysis is the technique, then those factors convertible into financial equivalents can be included in the quantitative analysis, but other factors should be considered in a qualitative manner in reaching a decision.

However, in a complete analysis each of the factors have to be expressed in the same units. These units can be dimensionless quantities (such as used in multiattribute utility analysis), or values could be expressed in *equivalent years of life lost*. Conventionally in cost-benefit approaches values are expressed in monetary units. However, it is the *relative values* placed on the components and their *weighting* one to another that is important, rather than the absolute unit in which they are quoted. Indeed, whatever unit is used can normally be readily converted to other units, such as *equivalent years of life lost* or *utilities*.

3.2.2 Non-radiological protection factors

Non-radiological protection factors are defined as those which are not related to the level of radiological protection achieved by protective measures. It is very difficult to generalize about these factors, although they can have an important or even overriding influence on the decisions taken.

Most intervention is disruptive to normal social and economic life. Change may cause anxiety, which can be harmful to health and well-being. However, the absence of protective measures can also cause anxiety, which is often exacerbated by a lack of objective information. These effects are non-radiological, are not easily quantifiable, will vary markedly between countries, and in any case will normally have opposing influences on the choices of intervention levels. They include the following factors:

- the perception of the hazard posed by the radiation from environmental dispersed radioactive materials,
- psychological impacts,
- the reassurance provided by the implementation of the countermeasure,
- the anxiety caused by its implementation,
- the individual and social disruption resulting from its implementation, and
- political considerations.

Although some of these factors to a certain extent are related to the level of protection achieved they are all considered to be non-radiological protection factors. The political input, however, is always deemed to include only non-radiological protection factors.

3.3 Decision making on protective measures

The overall health protection of people after an accident should be based on an optimized countermeasure strategy, which would include not only radiation protection factors but also other factors of political, psychological and social nature. This overall optimization of the *total health protection* is the responsibility of the decision maker(s) with guidance from radiation protection experts as well as experts in the fields of social and psychological sciences. The inclusion of these other factors in an overall optimization of health protection after an accident is thus a *discipline for decision makers* rather than being an extension of the radiation protection philosophy.

3.3.1 Justification and optimization of radiation protection

In existing exposure situations, *i.e.*, existing at the time when control procedures are being considered, the choice of action is limited. The most effective action, that applied at the source, is rarely available and controls have to be applied in the form of intervention. The system of radiological protection for intervention is based on the following general principles:

(a) *The proposed intervention should do more good than harm, i.e. the reduction in detriment resulting from the reduction in dose should be sufficient to justify the harm and the costs, including social costs, of the intervention (justification of intervention).*

(b) *The form, scale, and duration of the intervention should be optimised so that the net benefit of the reduction of dose, i.e. the benefit of the reduction in radiation detriment, less the detriment associated with the intervention, should be maximised (optimization of intervention protection).*

Dose limits do not apply in the case of intervention. The process of justification and optimisation both apply to the protective action.

Justification is the process of deciding that the disadvantages of each component of intervention, *i.e.*, of each protective action or, in the case of accidents, each countermeasure, are more than offset by the reductions in the dose likely to be achieved. The application of the justification principle is illustrated in Appendix B for clean-up of contaminated urban areas.

Optimisation is the process of deciding on the method, scale and duration of the action so as to obtain the maximum net benefit. In simple terms, the difference between the disadvantages and the benefits, expressed in the same terms, *eg*, monetary terms, should be positive for each countermeasure adopted and should be maximized by setting the details of that countermeasure.

The cost of intervention is not just the monetary cost. Some remedial actions may involve non-radiological risks or serious social impacts. For example, the short-term removal of people from their homes is not very expensive, but it may cause the temporary separation of members of a family and result in considerable anxiety. Prolonged evacuation and permanent relocation are both expensive and traumatic.

The benefit of a particular countermeasure within a programme of intervention should be judged on the basis of the reduction in dose achieved or expected by that special countermeasure, the avertable dose. If the total dose to some individuals is so high as to be unacceptable in any circumstances, *eg*, doses causing serious deterministic effects or a very high probability of stochastic effects, the feasibility of additional countermeasures influencing the major contributions to the total dose should be urgently reviewed.

(a) Application of optimization principle

The optimized protection against radiation induced stochastic health effects in an intervention situation would - according to the recommendations from the international radiation protection organisations ICRP [29] and IAEA [21] - include the avertable dose and the monetary costs of the achieved dose reduction.

A simplified optimization of radiation protection in terms of avertable dose and monetary costs of the protective measure is elaborated below to *illustrate the methodology.* In Section 3.3.2 the methodology is expanded to illustrate that the optimization of *overall health protection* should include *both* radiological and non-radiological protection factors at the same time to avoid a sub-optimized radiological and non-radiological protection.

If the effective dose accumulating per unit time without any protective action is $\dot{E}(t)$, then the avertable dose during the time period $\tau = t_2 - t_1$ during which the countermeasure is in action would be:

$$\begin{aligned} \Delta E(\tau) &= \int_{t_1}^{t_1+\tau} \dot{E}(t)\,\mathrm{d}t \\ &= E(t_1+\tau) - E(t_1) \qquad (1) \end{aligned}$$

It is assumed here that the countermeasure is 100% effective during time τ.

The monetary costs of the countermeasure during the time period τ can be expressed as the sum of a fixed cost component, C_0, and a time running cost component, c:

$$C(\tau) = C_0 + c\,\tau \qquad (2)$$

The net benefit of the protective action, B, is the difference between the equivalent monetary cost of the doses averted by the protective action and the monetary costs of that action:

$$B(\tau) = \alpha\, [E(t_1+\tau) - E(t_1)] - [C_0 + c\,\tau] \tag{3}$$

where α is the equivalent monetary value of avoiding a unit radiation dose.

The optimized level of protection is achieved when the protective action is introduced at time t_1 and suspended after having been in action for a time period, τ. The maximum net benefit can be found from:

$$\frac{\mathrm{d}B(\tau)}{\mathrm{d}\tau} = \alpha\,\dot{E}(t_1+\tau) - c = 0 \tag{4}$$

The intervention level for countermeasure suspension when *only* radiation protection factors are taken into consideration is thus given as:

$$IL_{rad} = \dot{E}(t_1+\tau) = \frac{c}{\alpha} \tag{5}$$

The cost parameters c and α are likely to be correlated to national wealth and thus susceptible to a relatively large variation between countries. However, the ratio c/α would in general be much less sensitive to geographical location than either the value of c and α alone.

The concepts of *Intervention Level*, *Operational Intervention Level* and *Action Level* are summarized below.

(b) Intervention Level (IL)

Intervention level refer to the dose that is expected to be averted (avertable dose) by a specific countermeasure over the period it is in effect. If an intervention level is exceeded, *i.e.*, if the expected avertable individual dose is greater than the intervention level, then it is indicated that the specific protective action is likely to be appropriate for that situation. Intervention levels are specific to accident situations. The intervention level can be defined as follows [20]:

> *Intervention level is the level of avertable dose at which a specific protective action or remedial action is taken in an emergency exposure situation or a chronic exposure situation*

The intervention level for a specific countermeasure can be determined from optimization as indicated above. The outcome of an optimization for a protective action continuing over a prolonged time period would be the intervention level for lifting the countermeasure as well as the time interval over which it would be in action. The concept of an intervention level is illustrated in Fig. 5 [21].

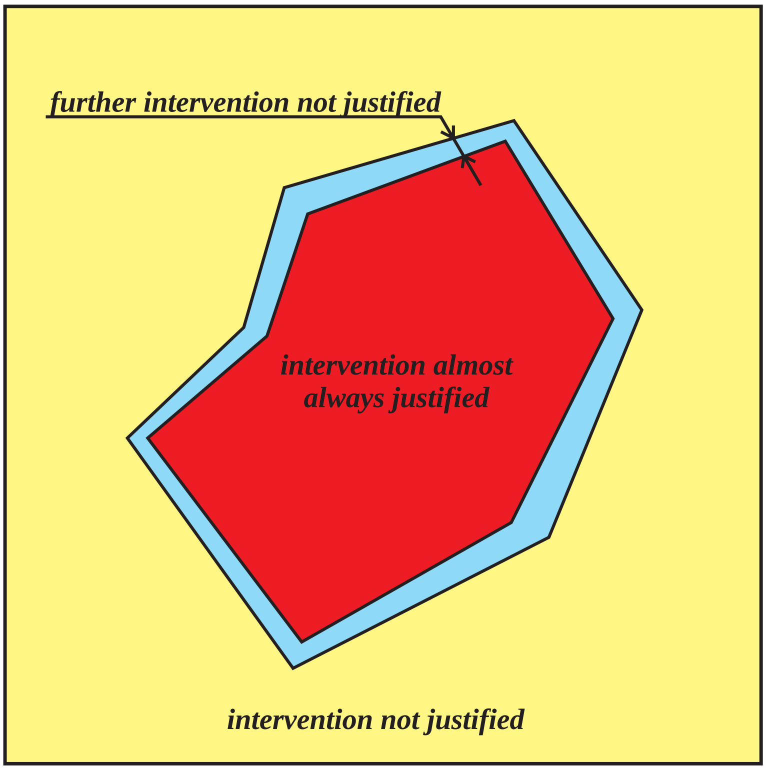

Figure 5. Concept of intervention level. Intervention is always justified for the inner area. This area can delineate a population to be evacuated, the amount of foodstuffs to be banned etc. In the optimization process this area will be enlarged until the marginal increase in avertable doses becomes just less valuable than the increased marginal costs. The optimized intervention level therefore corresponds to the differential dose saving at the border between intervention and non-intervention areas.

The Intervention Level is specified in terms of the dose that is anticipated to be averted by the associated protective action and ILs are specified separately for different protective actions. If an IL for a specific protective action is anticipated to be exceeded, *i.e.*, if the expected avertable individual dose is greater than the IL, it is then indicated that the protective action is likely to be appropriate for that situation. The avertable doses would therefore need to be at least equal to the IL.

The practical interpretation of an IL will therefore be the dividing line between areas in which intervention is not justified and areas in which intervention is justified and by which the resulting avertable doses ranges from the IL and - at least in theory - to infinity (see Fig. 5). Strictly speaking, intervention may happen to be only at the edge of being justified in the inner areas if the upper boundary of the range is so close to the intervention level that some initial, non-incremental costs may need to be considered.

(c) Operational Intervention Level (OIL)
Because of the inherent difficulty of forecasting doses that could be averted, there is a merit in establishing surrogate quantities derived from the intervention level. The relationship between these quantities and the avertable dose will vary considerably with the circumstances of the accident and nature of contamination. The operational quantities would, therefore, be both accident and site specific,

depending on types of radionuclides, environmental half-lives, transfer factors of deposited activity, location factors and filtering factors for housing conditions, etc. However, OILs would still be related to the avertable dose.

Operational intervention levels are expressed in quantities that can be more easily assessed at the time of decision on intervention such as dose rate, activity concentration, surface contamination density, etc. OILs are related to the dose that could be averted by a *specific* countermeasures like evacuation, relocation and banning of foodstuffs.

(d) Action Level (AL)

Action level refer to different protective measures or strategies like agricultural countermeasures or radon reducing measures in houses and they relate to the residual dose without any remedial actions taken. The action level can be defined as follows [20]:

> *Action level is the level of dose rate or activity concentration above which remedial actions or protective actions should be carried out in chronic or emergency exposure situations*

Action levels are levels above which remedial actions are taken and below which they are not. An action level is set such that the dose averted by taking the remedial action is always worthwhile in terms of the costs and other disadvantages involved. Justified action levels would begin at the minimum value of the avertable individual dose at which the remedial action is just beginning to do more good than harm.

The action level can thus be defined as the lowest level at which remedial actions to reduce doses are justified and optimized. The equivalent definition would be that the action level is equal to the maximum acceptable level of dose attributable to the contamination without any protective actions taken. If an action level is exceeded, it is indicated that some form of remedial action specific to the situation considered is likely to be appropriate. An action levels has, therefore, the same character as an operational intervention level.

The concept of an action level/operational intervention level is illustrated in Fig. 6.

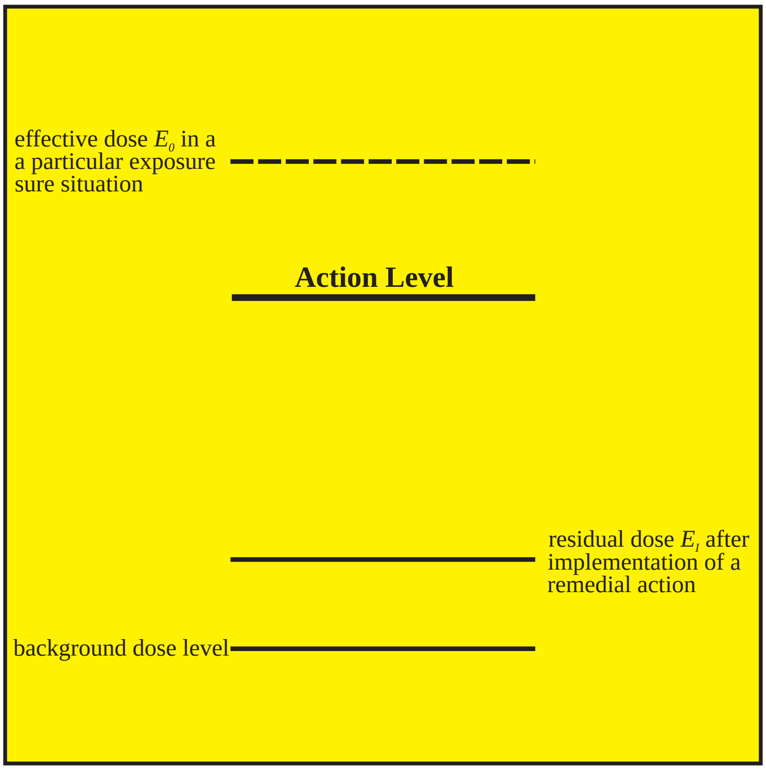

Figure 6. Concept of an Action Level/Operational Intervention Level. This operational quantity corresponds to the maximum acceptable residual dose without any remedial action which is equivalent to the minimum avertable dose by the remedial action.

3.3.2 Justification and optimization of health protection

Socio-political and psychological factors indeed may well contribute to, or even dominate, decisions on countermeasures. The competent authorities responsible for radiation protection should therefore be prepared to provide the radiation protection input (justification and optimization of the proposed protective actions on radiological grounds) to the decision making process in a systematic manner, indicating all the radiological protection factors already considered in the analysis of the protection strategy. In the decision process the radiological protection and the socio-political, psychological factors and political factors should each be taken into account only once to avoid the same political factors being introduced in several places.

Radiological protection factors have been used in developing international numerical guidance on intervention levels for implementing countermeasures to reduce doses after a nuclear or radiological emergency, but explicit guidance is not provided on how psychological and social factors should be included in the optimization of overall health protection. However, the optimization of radiation protection and certain psychological and social protection should probably not be carried out independently as separate and independent entities, as the overall health protection would depend on both radiological and non-radiological protection factors.

The overall health consequences of a nuclear or radiological emergency include the increased stochastic risks directly attributable to the accident. They also include the perception of the hazard posed by radioactive materials dispersed in the environment and enforced changes of lifestyle which lead to increases in psychological strain in the affected population. Such increases may in turn lead directly or indirectly to increased illness.

In situations where a dose-reducing countermeasure has already been implemented, and has been found to create so much strain that a net harm has been the result, *i.e.*, the psychological harm introduced by the countermeasure more than offsets the benefit of the dose reductions, it may be optimal not to reduce doses, or even increase doses, in order to reduce the strain and so provide an overall net benefit. For example, some relocation strategies in the former USSR moved people to areas of high radon dose such that their total annual radiation exposure after the countermeasure was greater than if they had remained in the contaminated areas. Such a strategy may result in improved overall health due to a reduction in perceived risk or due to the psychological benefit from the countermeasure that would more than offset the increased radiation risk.

The optimization of an overall health protection in which both radiological and non-radiological protection factors are included at the same time is shown above in Fig. 7.

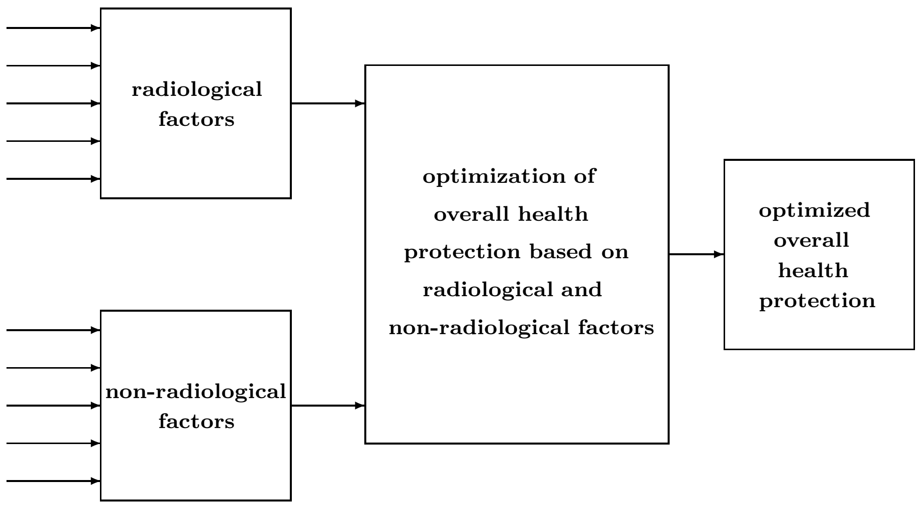

Figure 7. Optimization of overall health protection based on radiological and non-radiological protection factors after a radiological or nuclear emergency.

The independent optimization of radiological and non-radiological factors where the results of the two procedures are combined to arrive at a sub-optimum course of action is shown below in Fig. 8.

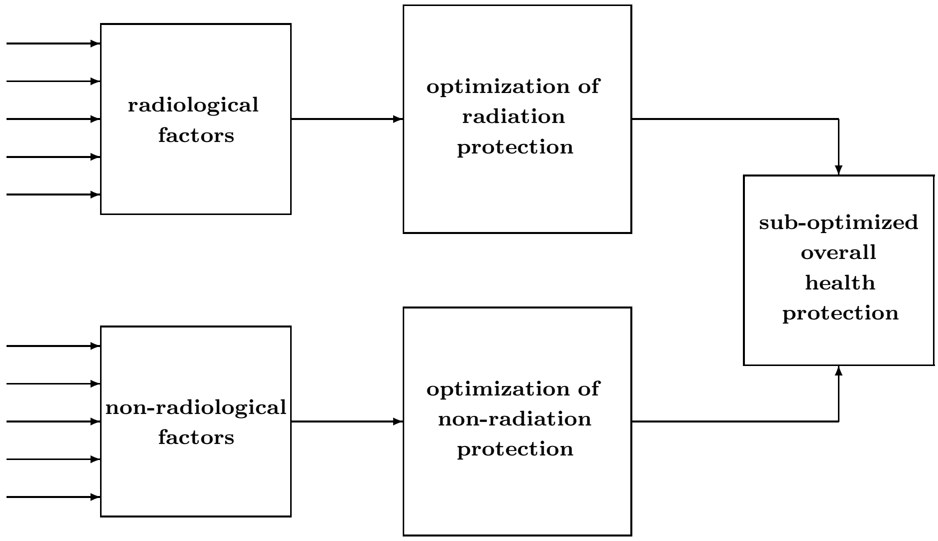

Figure 8. Optimization of radiation protection and non-radiation protection resulting in a sub-optimized overall health protection after a radiological or nuclear emergency.

The optimization of overall health protection would include non-radiological protection factors like psychological and other less tangible factors. For illustrative purposes it is postulated here that the psychological harm introduced by countermeasures is proportional to the *residual dose* remaining when the countermeasures are suspended at time $t_1 + \tau$. The residual dose, E_R, can be expressed as:

$$\begin{aligned} E_R(t_1+\tau) &= \int_{t_1+\tau}^{\infty} \dot{E}(t)\,\mathrm{d}t \\ &= E_{total} - E(t_1+\tau) \end{aligned} \quad (6)$$

where E_{total} is the total dose from the start of the accident *without* any countermeasures.

The risk of psychological harm per unit residual dose is here assumed to be a constant, *i.e.* the larger the residual dose the larger the psychological harm in the affected population. The equivalent monetary cost of avoiding a unit *residual* dose to avoid psychological induced health effects is here called β. The net benefit of introducing countermeasures that in addition to reduce radiation doses also reduce psychological induced health effects due to the residual dose can be found by expanding Eq. (3) as:

$$\begin{aligned} B(\tau) &= \alpha\,[E(t_1+\tau) - E(t_1)] - [C_0 + c\,\tau] - \beta\,E_R(t_1+\tau) \\ &= \alpha\,[E(t_1+\tau) - E(t_1)] - [C_0 + c\,\tau] - \beta\,[E_{total} - E(t_1+\tau)] \end{aligned} \quad (7)$$

The optimised protection is achieved when countermeasures are introduced at time t_1 and suspended after having been in action for a time period τ. The maximum net benefit can be found from:

$$\frac{\mathrm{d}B(\tau)}{\mathrm{d}\tau} = \alpha\,\dot{E}(t_1+\tau) - c + \beta\,\dot{E}(t_1+\tau) = 0 \quad (8)$$

The intervention level, IL, for countermeasure suspension when *both* radiation protection factors *and* psychological factors related to the residual dose are taken into consideration is thus given as:

$$IL_{rad+psy} \quad = \quad \dot{E}(t_1 + \tau) = \frac{c}{\alpha + \beta} \tag{9}$$

It appears that an overall optimization where both radiological and non-radiological protection factors are included - corresponding to Fig. 7 - results in an optimized level of overall protection which is different from the sub-optimized levels from an optimization of either radiological or psychological protection alone. Such sub-optimizations would result in the following intervention levels:

$$IL_{rad} = \frac{c}{\alpha} \quad \text{and} \quad IL_{psy} = \frac{c}{\beta} \tag{10}$$

With the above simplified assumptions it appears that the optimized intervention level for overall health protection will be less than the optimized levels of protection when only radiation protection factors or psychological factors are included alone.

3.4 Unresolved issues

Unresolved issues, both in the context of practical management and the practicability of radiological guidance, have been identified to be the interaction between radiological and non-radiological protection factors in decision-making. Both radiological and non-radiological protection factors will influence the level of protective actions being introduced. Social-psychological countermeasures are a new category of action, in the sense that social protection philosophy has not yet been developed to fully include their application after a nuclear accident. From the experience in CIS following the Chernobyl accident, the need for social-psychological countermeasures is obvious.

It has been suggested that the inclusion of such countermeasures into the intervention decision making framework should be as a part of the radiation protection framework. It is argued here that optimization of the overall health protection is not a question of developing radiation protection philosophy to fully include socio-psychological factors. It is rather a question of including these factors - in parallel with the radiological protection factors - in cooperation between radiation protection experts and psychological specialists under the responsibility of the decision maker.

The overall health protection of people after a nuclear accident or radiological emergency should thus be based on an optimized countermeasure strategy, which would include not only radiation protection factors but also other factors of political, psychological and social nature. This overall optimization of the total health protection is the responsibility of the decision maker(s) with guidance from radiation protection experts as well as experts in the fields of social and psychological sciences. The inclusion of these other factors in an overall optimization of health protection after an accident is thus a discipline for decision makers and not an extension of the radiation protection philosophy.

4 International and CIS Intervention Criteria

The protective measures taken in the CIS after the Chernobyl accident included early countermeasures like sheltering, administering stable iodine and evacuating those parts of the population who might be exposed to radiation from the plume and from deposited activity. Long-term countermeasures, such as relocation and foodstuff restrictions, were taken to mitigate the effects of lower, but still significant levels of radiation from surface and soil contamination. The levels at which these measures were introduced were based on different rationales, and the levels have been changed by the competent authorities during the years following the accident.

The basic intervention philosophy in the three republics have been under constant evolution. At present, the different concepts being developed include - in addition to radiation protection factors - social protection considerations. It is also considered to unify the systems of radiation protection for interventions and practices.

4.1 Intervention criteria in the former USSR

The first decision-making criteria in the USSR were developed in the 60-es and adopted by the USSR Public Health Ministry (PHM) in December 1970. The last pre-Chernobyl revision was approved officially by the PHM in August 1983. "Criteria for urgent decision on measures to protect the population in the event of a reactor accident" were designed for pre-planning of countermeasures at the early phase after an accident. The criteria addressed the first hours and days, but no more than two weeks after the release of radioactive materials into the environment, with the aim to prevent both deterministic health effects (at that time in terms of "non-stochastic effects") and a high probability of late stochastic effects, as well as to reduce economical losses caused by radioactive contamination. The Criteria included a two-tier system for intervention levels in terms of external dose (0.25 - 0.75 Gy), thyroid dose (0.3 - 2.5 Gy) and derived intervention levels (DILs) for intake of ^{131}I via inhalation and ingestion of foodstuffs, including a peak value of activity concentration in milk.

The background for the development of the Criteria, the derivation and interpretation of numerical values of intervention levels, as well as the comparison with international recommendations (including those updated after the Chernobyl accident) are described in detail in the Final Report on JSP 2/TASK 1 [35]. Conceptually the Criteria were in line with the radiation protection principles for intervention adopted by international organizations (ICRP, IAEA). The main methodological difference was that the Criteria assumed conservative (pessimistic) assessment of *projected doses* so actual doses would not be in excess of those predicted. Consequently, there was an essential safety margin when comparing the Criteria dose levels with those based on a realistic assessment of projected or avertable dose.

The Criteria were used in decision making on evacuation of the 30-km-zone and on other urgent countermeasures in the first days after the Chernobyl accident, including the introduction of temporary permissible levels (TPLs) of ^{131}I content in milk and other foodstuffs.

The chronology of major events in the decision making on countermeasures and social policy after the Chernobyl accident is listed in Table 6.

Table 6. Main events in decision making related to the Chernobyl accident (USSR, Russia).

Date	Main event
4 August 1983	Decision making criteria (DMC), 2nd revision
27 April - 6 May 1986	Urgent protective actions in line with the DMC
5 May 1986	DILs for ^{131}I in foodstuffs
12 May 1986	Annual dose limit for first year (100 mSv)
30 May 1986	DILs for β-activity in foodstuffs (TPL-86)
23 April 1987	Annual dose limit for second year (30 mSv)
15 December 1987	DILs for $^{134+137}Cs$ in foodstuffs (TPL-88)
18 July 1988	Annual dose limit for 1988-1989 (25 mSv/year)
22 November 1988	Lifetime dose limit (LTD) of 350 mSv
25 April 1990	USSR Supreme Soviet rejects LTD-concept
22 January 1991	DILs for $^{134+137}Cs$ and ^{90}Sr in foodstuffs (TPL-91)
8 April 1991	Approval of annual dose concept
15 May 1991	RSFSR Supreme Soviet Act on social protection of people affected by the Chernobyl accident
21 July 1993	Revised DILs for $^{134+137}Cs$ and ^{90}Sr in foodstuffs (TPL-93)
10 August 1993	Concept of radiation protection of people and economic activities in the territories affected by the Chernobyl accident
22 September 1993	Criteria for registration of persons suffered from exposure to radiation and exposed to radiation
17 July 1995	Concept of radiological, medical, social protection and rehabilitation of people affected by exposure from radiation accidents

The table contains the main official documents on regulations for basic intervention levels in terms of annual or lifetime doses, temporary permissible levels (TPL) of radionuclides in foodstuffs and officially approved concepts for management of territories affected by the Chernobyl accident.

The period from 1986 to the early 1990es was reviewed in a previous JSP 2

Report [16]. In the first half of this period decision policy was based on radiological principles, although more conservative than those originating from optimization.

In the first few years after the accident, γ-exposure rate in air, surface contamination density and activity concentration in foodstuffs were used as main criteria for the introduction of protective actions.

In 1988 the total dose from all exposure pathways due to the accident were proposed as a criterion for decision making on protective actions. In accordance to the recommendations of the National Committee on Radiation Protection of USSR (NCRP), the first of these dose criteria was the so-called "lifetime dose concept". This dose was a conservatively estimated total dose from all exposure pathways due to the accident over a time period of 70 years under normal living conditions in the contaminated territories. A lifetime dose level of 350 mSv was suggested.

Due to the negative reaction of the public and local authorities the lifetime dose concept - referred to as the "35-rem concept" - was officially rejected by the USSR Supreme Soviet (Parliament) in April 1990. In the years 1990-1991 some differences in intervention criteria between the affected Soviet Republics, now CIS states, started to appear.

4.2 Evolution of intervention criteria in Russia

The period since the late 80es was characterized by strong influence of non-professional political and social forces on decision making on countermeasures and social protection of populations living in contaminated territories. Under strong pressure of socio-psychological and political factors, requirements for radiation protection were more and more strict, which resulted in discrepancies between the implemented decisions and the internationally accepted radiation protection principles [15].

After the official rejection of the lifetime dose concept another concept was worked out as a compromise between the radiological principles and the influence of non-professional forces [6]. Intervention levels in terms of effective annual individual doses, E_{an}, formulated in a concept (Concept-91) approved officially in April 1991 by the All-Union and Russian Federation governmental bodies, are still in action. The values of 1 mSv/y and 5 mSv/y were conceptually formulated as a non-action level and a control level, respectively.

If E_{an} exceeds 1 mSv, a complex of protective measures should be carried out. These measures should simultaneously be aimed at relaxing the socio-psychological tension and stress. The achievement of these goals should be based on optimization with the condition that the average individual effective dose should not exceed 5 mSv in 1991. This control level should, as far as possible, be reduced in the following years to 1 mSv/y. The control level of 5 mSv/y was *not* established as a criterion for compulsory relocation although in territories where the annual effective doses would exceed 1 mSv the population had the right to be relocated. One of the main objectives of the concept was that the implementation of the State Union-Republic program should avoid mass relocations. Based on this concept the Chernobyl All-Union and republican laws were worked out and adopted in 1991.

It should be noted that some important issues of the Chernobyl All-Union and Republican laws appeared to be serious self-contradictory and also in contradiction with the concept. Both the annual effective dose and the surface contamination density were used for decision making on protective measures including compulsory relocation. Radiological and social protective measures should be implemented in territories with a surface contamination density of ^{137}Cs larger than 37 kBq·km^{-2}.

Due to the contradictions the following would be the result:

- areas officially recognized as suffering from the accident increased many times: from three to seventeen regions with an increase in population from about 100,000 to 2.7 millions people,
- additional compulsory mass relocations were decided,
- optimum levels of protection from a complex of countermeasures were impossible to achieve, and
- additional social problems and negative consequences were created in the affected population.

Derived intervention levels (DILs) for foodstuffs (in terms of temporary permissible levels, TPLs) are revised every two years. The evolution of DILs in USSR and Russia are shown in Table 7.

Table 7. Temporary Permissible Levels (TPL) for radiocesium in foodstuffs.

Foodstuffs	TPL (Bq/kg)[a]				
	USSR			Russia	
	1986[b]	1988	1991	1991	1993
Milk	3,700[c]	370	370	370	370
Meat, fish, eggs	3,700	1,800-2,960	740	740	600
Fat	7,400	370	185	37	370
Potatoes, vegetables, fruits	3,700	740	600	74	600
Cereal products	370	370	370	370	370
Wild berries, mushrooms	18,500	1,740	148	148	600
Infant food	-	370	185	37	185
Drinking water	370	18.5	18.5	3.7	-

[a] sum of ^{134}Cs and ^{137}Cs activity
[b] total β-activity
[c] 370 Bq/kg from 1 November, 1986

The last revision was made in 1993. The original draft of TPL-93 suggested a structure and also numerical values close to those for imported foodstuffs in CEC and Codex Alimentarius Commission (FAO/WHO). Two categories of food were suggested instead of a long list of food items in the preceding TPLs from 1986 to 1991. But the State Committee on Sanitary Supervision (SCSS) inserted into the "Milk and infant food" category a variety of other food items and insisted on the introduction of a separate category for infant food and on lowering the numerical values for this kind of food by a factor of two for ^{134}Cs/^{137}Cs and a tenfold reduction for ^{90}Sr. TPL-93 were officially approved by the SCSS in July 1993. The listing of food items and numerical values of TPL-93 are presented in Table 8.

Table 8. Temporary Permissible Levels (TPL) for content of ^{134}Cs, ^{137}Cs and ^{90}Sr in foodstuffs (TPL-93).

Foodstuffs	TPL (Bq/kg) (nCi/kg)	
	^{134}Cs, ^{137}Cs	^{90}Sr
Milk, sour milk products, cream, cottage cheese, cream butter, bread, bread products, cereals, sugar, fat (vegetable and animal), margarine	370 (10)	37 (1)
All kinds of specific infant food (ready for consumption)	185 (5)	3.7 (0.1)
Other food products	600 (16)	100 (3)

There are some comments in the official document, the most essential are as follows:

- TPL-93 are derived in such a way, that even in unrealistic conditions of permanent annual consumption of each food product with contamination at the TPL level, the committed effective dose would not exceed 5 mSv from $^{137+134}$Cs and 1-2 mSv from ^{90}Sr.
- TPL for tea, honey, medicine plants and other products with per capita consumption less than 10 kg/y are 10 times higher than for "other food products"; TPL for concentrated, condensed and dried milk is two times higher than shown in the table for "other products".

TPL-93 is formally designed for a two year period. At present, a new revision is in progress.

4.2.1 Countermeasures

The main long-term protective measures taken after the Chernobyl accident included relocation of people from the most contaminated areas as well as continuing restrictions of foodstuffs contaminated with radiocesium.

Relocation

Evacuation was not justified in any Russian territory according to the decision making criteria for urgent protective measures (DMC-83), as it was for the 30-km zone around the Chernobyl nuclear power plant. In August 1986 four villages with a total population of 185 persons were resettled. The decision was justified by the conservative assumption that countermeasures (other than resettlement) provided no guarantee to prevent doses above 100 mSv/y in villages with the highest level of contamination.

The next step in organized relocation was a decree in September 1989 on a first order relocation of settlements with a surface contamination density (S) of ^{137}Cs greater than 40 Ci/km^2. A total of 44 settlements with a population of 6,800 were relocated. The Federal Law-1991 confirmed obligatory relocation from areas with a surface contamination density $S > 40$ Ci/km^2 and the right to relocation in territories with $S > 15$ Ci/km^2. In a previous JSP 2 Report [19], population distributions on surface contamination density of ^{137}Cs, on annual effective dose in 1991 as well as on avertable lifetime dose were presented. 84,000 people lived in 1991 in the zone of relocation with $S > 15$ Ci/km^2, half of them in the city of Novozybkov where the annual individual doses were less than 1 mSv. The annual individual effective doses in 1991 exceeded 1 mSv in settlements with a total population of 105,000. About 37% of this population lived in the zone of relocation, 44% in the zone of right for relocation and the rest in territories with a contamination density $S < 5$ Ci/km^2.

In 1991 a total of 7989 persons were officially relocated from contaminated territories of the Bryansk Region, including zones of relocation and zones of right to be relocated (data from the Bryansk Regional Department of Statistics). In the following two years the number of relocated people were 4,632 and 2,601. The total number of relocated people during a period from 1989 to 1993 was 36,084 with a maximum value in 1990 of 17,162. The obvious sharp decrease in relocation from 1990 to 1993 is the result of not only the economical and organizational difficulties, but also from the fact that the attitude of the population to relocation and to the possibilities of healthy living conditions in the contaminated areas became more realistic.

Practically all people in the affected regions who wanted to be relocated due to concern and fear have now been relocated (totally 47,000 people in the period 1986-1995). Moreover, in the later years (1993-1995) the number of people moving into the contaminated areas of Bryansk region, including those returning to their previous sites, prevailed against the number of people leaving the zones of relocation and of right for relocation. This migration process is caused by a general decrease in living conditions and essential benefits and compensations for those residing contaminated territory. Apparently, an actual curtailment of the relocation program should be considered positively. Cost-benefit analyses showed that the monetary equivalent of doses averted by relocation of people from the zone of obligatory relocation is 40 times less than the actual expenses for relocation in 1989-1993 [41].

Food control

Current values of activity concentration of radiocesium in milk and other locally produced foodstuffs, excluding "wild" food products, are almost everywhere lower than TPL-93 levels. In the most contaminated areas of Russia - the western districts of the Bryansk Region - only 0.7% of the milk samples taken in 1994 were contaminated in excess of TPL, while in 1986 this index was 75%. The average value of the annual internal dose from ^{134}Cs and ^{137}Cs calculated from whole body measurement data and averaged for rural population of the "strict control zone" (now defined as the relocation zone) decreased from 6 mSv in 1986 to 0.5 mSv in 1992 [34]. Thereafter, a marked increase in radiocesium body content was observed, resulting in a increase of the internal doses in 1993-1995 up to a factor of two and more in some settlements compared with the internal doses in 1991-1992. This increase can be explained by the following reasons:

(1) The supply with foodstuffs from uncontaminated regions (mainly milk and meat products) to local people from uncontaminated regions is sharply reduced in view of, firstly, economical circumstances, and secondly, the fact that there are no reasons to restrict the use of local foodstuff production when its contamination is lower than TPL values.

(2) The change in Russian economy resulted in a strong rise in foodstuff prices, which forced rural people to resume their private farming activities, previously disturbed by countermeasures. The number of "private" cows raised more than five times after the lowest level in 1991.

(3) There is also a growth in consumption of "wild" food items: mushrooms, berries, fish from local water basins, and game. This kind of natural produce

is characterized by relatively high levels of contamination with radiocesium. Currently (1993-1995) the activity concentration in various kinds of edible mushrooms shows a large variation, from 0.2 to 220 kBq/kg, and in berries from 0.007 to 7 Bq/kg. Analyses of questionnaires on food habits in the local population have given the following distribution of intake of radiocesium via foods. Consumption of milk varies from a few per cent to 43%, in average 22%. The contribution of mushrooms and wild berries to internal doses was in average 41%, varying from a few per cent to 63% [36].

Relatively high levels of radiocesium content in mushrooms and berries is a point of discussion with sanitary supervision inspectors. It is noted in the comments to TPL-93 that for food items with per capita consumption less than 10 kg/y, TPL should be 10 times higher than values set for "other food products" (see Table 8 and the text following the table). Questionnaires cited above have given average values for people from 13 surveyed rural settlements of 5.7 kg/y for mushrooms and 1.0 kg/y for wild berries. The maximum values for one of the villages was 19.2 kg/y for mushrooms and 2.5 kg/y for berries. The "mushroom problem" would be a matter of consideration in the drafting of a new TPL-96 to replace TPL-93 (in view of the procedure to review TPLs once every two years).

4.2.2 Development of intervention concepts for later phases

Starting from the late 1980es the actually authorized decisions were made under a strong pressure of social, psychological and political factors, resulting in unreasonable increases in radiation protection demands. The zones affected by radiation protection and social assistance measures have therefore expanded giving the public the false impression that the radiation hazard was underestimated in the first months and years following the accident. In the Russian Federation the number of residents in territories affected by the implementation of radiation and social protection measures raised from 88,000 in 1986 (territories with ^{137}Cs contamination $S > 555$ kBq/m^2 where annual doses in excess of 100 mSv were conservatively projected if no countermeasures were undertaken) to 1.5 millions in 1991 and 2.7 millions in 1993 (territories with $S > 37$ kBq/m^2 in line with the legislative definition of contaminated zones in 1991).

A paradoxical phenomenon did arise. Instead of changing to a recovery phase following the accident, the scale of intervention did increase. This phenomenon was a result of both current socio-political processes in the USSR/CIS/Russia and lack of methodology for decision making at the late stages of the accident situation when return to normal living conditions in areas affected by radioactive contamination were needed. This need has in the latest years lead to development of a conceptual basis for rehabilitation of territories affected by radioactive contamination. The aim of this new development is to optimize social protection measures and the number of people involved in social attention related to the Chernobyl accident, in line with actual radiological criteria and available resources.

The social impact of the Chernobyl accident and the decisions on social assistance to the affected population resulted in an increase in public anxiety because of situations created in the past by the Kysthym accident, radioactive discharges into river Techa in Urals and by nuclear weapons tests. New concepts relating to all situations with a wide-scale radioactive contamination were therefore needed. This stage of conceptual evolution started in the early 1990es. The essential content of the "Concept-93" has been described in a previous JSP 2 Report [18]. "The concept of radiation protection of the population and economic activities in the territories affected by radioactive contamination" was officially approved by the Russian Federation Council of Ministers Decree from 10 August, 1993 as a base for development of legislation and standardization in social protection of people "suffering from radioactive contamination and for rehabilitation of the territories affected by radioactive contamination". The Prime Minister ordered to direct the Concept towards involved Ministries and regional administrative authorities.

The following conceptual step in the evolution of regulation to manage territories and people affected by abnormal exposure to radiation was the development of a "Concept of radiation, medical, social protection and rehabilitation of population affected by accidental exposure to radiation". The Concept was approved by the Russian Scientific Commission on Radiation Protection. In July 1995 the Government of the Russian Federation recommended "to use this concept for elaboration of regulating acts and target programs in the field of social protection of people affected by accidental radiation". The terms "accidental radiation" and "exposure to accidental radiation" meant here exposure to radiation from environmental radioactive contamination following past radiological accidents and nuclear weapons tests.

The Concept-93 was aimed mainly to regulate activities and restrictions in contaminated territories. The Concept-95 formulated scientific principles and methods for the practical realization of protection of involved people, with the aim to prevent or mitigate health consequences of the past radiological incidents, to eliminate or minimize psychological stress, and to compensate individual material and moral losses. The list of radiological protective measures was related to the latest stage of post-accident management in contaminated territories. The latter is defined as the areas where a current annual effective dose to local population is equal to or above 1 mSv.

Contaminated territories are subdivided into two zones in accordance with the value of annual effective dose in the absence of countermeasures such as engineering decontamination of settlements and supply by radiologically "clean" foods:

- *zone of radiation control (1-5 mSv/y)*, and
- *zone of restricted residence (5-20 mSv/y).*

Radiological monitoring of the environment, agricultural products and doses to the population is carried out in both zones, as well as countermeasures to reduce doses to the population in line with the principle of optimization of intervention. In the zone of restricted residence, radiation risk and undesirability for families with children to move into the zone would be explained to local residents and to persons moving to live in this zone. The residents are assisted to resettle outside the zone upon their own decision. The upper dose bound for this zone is truncated at a level of 20 mSv. The reason is that today there are no settlements in the Russian Federation with an average annual effective dose in excess of 20 mSv resulting from the Ural and Chernobyl accidents or from past nuclear weapons tests.

Concept-95 introduced definition of two categories of people affected by exposure to radiation:

- *exposed person* is an individual with acute (short-term) dose more than 50 mSv or with accumulated effective dose from chronic (prolonged) exposure in excess of 70 mSv.
- *suffered person* (victim) is an individual with deterministic health effects or with other diseases officially ascertained as consequences of radiation or of other circumstances of an accidental situation.

Both exposed and suffered persons should be included into the National radiation and epidemiological registry.

The Registry was previously officialized by the Decree of the Russian Federation Council of Ministers from 22 September, 1993 "On national registration of persons exposed to radiation and radiation effects as a result of the Chernobyl accident and other radiation-related disasters and incidents". The criteria for registration introduced in the appendix to this Decree were not the same as established later in the Concept-95.

For all people exposed to and suffered from radiation a system of health care and rehabilitation is suggested with special attention to suffered persons (victims) and to members of the "enhanced risk groups". Concept-95 defines these groups as persons with latent or evident pathologic manifestations and with high doses. A high dose is defined as an effective dose in excess of 250 mSv from acute exposure or 350 mSv from chronic exposure, as well as a thyroid dose more than 2.5 Gy for adults and 1.0 Gy for children, and in utero exposure to doses above 50 mSv.

Health protection suggests measures to raise a general and anti-cancerogenic resistance of human organism as well as measures to restrict the influence of other harmful factors than those of radiation. Psychological protection means improvement of public knowledge on radiation effects, possibilities to gain trustworthy and intelligible information on radiological situation, and foundation of psychological assisting centres in contaminated regions. A system of benefits and compensations should be established for exposed persons and for people living in settlements with an effective dose above 1 mSv/y. The Concept-95 includes also general recommendations for legal guarantee of the listed protective measures.

In case of transfer to new concepts (Concept-95) the number of people affected by social attention and benefits related to the consequences of the Chernobyl accident, would be sharply reduced. A total of 2.7 millions are living in 7544 settlements assigned to contaminated zones in line with the Law that is currently in action (territories of the Russian Federation with ^{137}Cs contamination more than 37 kBq/m^2). Current regulations provide a differential system of collective and personal benefits and compensations for all these territories and populations. It has been shown in a preceding JSP 2 Report that 105,000 people are living in settlements with an average annual effective dose in excess of 1 mSv in 1991 (Table 2 in [19]).

Taking into consideration the minor changes in doses during the latest years as well as actual demographic processes in the involved region, the number of people in settlements with current doses exceeding 1 mSv/y is now almost the same as in 1991, *i.e.*, about one hundred thousands. Therefore, 96% of the population currently assigned as living in contaminated zones will deprive of existing privileges. One may anticipate that the local authorities should categorically raise objections against a curtailment of the federal program in their regions. A negative response of the general public in the affected territories may also quite obviously be predicted. Anyway, in the best case, the introduction of the latest concept into practical realization will essentially need a transient period. In the worst case, a situation may arise similar to that in 1989-1990, when the lifetime dose concept (often referred as "35 rem concept") failed to be realized.

4.2.3 Revision of general decision making criteria

The Chernobyl experience and the latest international recommendations (ICRP Publications 60 and 63, IAEA Safety Series No. 109, Basic Safety Standards) were taken into consideration in drafting the new Russian Radiation Safety Standards (RSS-96), which was adopted 19 April 1996 to replace current RSS-76/87 [40]. The latter were worked out in 1970es with slight amendment in 1987, and they are no longer in line with the updated philosophy and standards in international radiation protection guidance.

The RSS-96 is conceptually in accordance with the ICRP Publication 60 and the Basic Safety Standards. The methodology of dose limitation in the RSS is differentiated to four kinds of situations with exposure to ionizing radiation: occupational and public exposure in normal operation with sources of ionizing radiation, exposure to natural background sources, medical exposure, and emergency exposure situations. In view of high social importance of dealing with emergency situations, it was agreed to include into RSS a separate section on radiological protection of the general public in case of a radiation accident. This section of the RSS draft is summarized below.

Justification and optimization principles for intervention similar to those in ICRP-60 have been formulated. Notwithstanding these principles, urgent protective actions should be mandatory in case if projected acute exposure may reach the level associated with possible clinically pronounced health effects (deterministic effects). The corresponding doses in 2 days are quoted from the Basic Safety Standards: 1 Gy to the whole body and 2 to 6 Gy to other single organs or tissues. Site-specific intervention levels should be justified in pre-planning emergency response for specified installations and accident scenarios.

In case of an accident resulting in off-site radioactive contamination of large territories, a zone of radiation accident (ZRA) should be established. ZRAs are defined as a territory where a projected exposure to radiation may exceed an effective dose of 5 mSv per year. Radiological monitoring should be carried out in ZRA, as well as protective measures to reduce radiation doses applying principle of optimization in intervention. A two-tier system of generic intervention levels has been formulated for both urgent countermeasures at the early stage of accident situation and long-term countermeasures at later stages of the accident. The numerical values of decision making criteria are presented in Tables 9-11: an upper level B above which the introduction of countermeasures is compulsory and a lower level A having the role of a non-action level. Detailed special guidance on management of radiological accidents is suggested to be worked out as safety guides for practical application of the RSS.

Table 9. Decision making criteria for urgent countermeasures at the early stage of an accident situation (RSS-96).

Countermeasures	Projected dose for 10 days (mGy)			
	Whole body		Thyroid, lungs, skin	
	Level A	Level B	Level A	Level B
Sheltering	5	50	50	500
Iodine prophylaxis				
Children	-	-	100	1,000
Adults	-	-	250	2,500
Evacuation	50	500	500	2,500

Table 10. Decision making criteria for relocation and food control (RSS-96).

Countermeasures	Avertable effective dose (mSv)	
	Level A	Level B
Restrictions in consumption of contaminated foodstuffs and drinking water	5 (first year) 1/y (following years)	50 (first year) 10/y (following years)
Relocation	50 (first year)	500 (first year)
	1000 for relocation period	

New basic recommendations applicable to the existing contaminated territories and possible future accidental situations are being developed to include all experi-

Table 11. Decision making criteria for food control in the first year after an accident (RSS-96).

Radionuclides	Activity concentration in foodstuffs (kBq/kg)	
	Level A	Level B
^{131}I, ^{134}Cs, ^{137}Cs	1	3
^{90}Sr	0.1	0.3

ence on liquidation of the consequences of nuclear accidents and nuclear weapons tests. The guidance will be based on both radiation and non-radiation risks and will be expressed in three sets of different intervention levels:

(a) General Intervention Levels (projected doses) establishing strategies of intervention;

(b) Specified Intervention Levels (avertable doses or risks) for radiation protection purposes;

(c) Specified Intervention Levels (residual doses or risks) for social protection purposes.

The last set of levels was primary introduced for social protection of the population in the Altai region affected by the nuclear weapons tests at the Semipalatinsk test site. Obviously, this set of levels should have a wider application and should be improved taking into account new data and new experience.

In addition to the general recommendations on intervention strategy and intervention levels, the specific recommendations on methodology of risk analysis for post-accidental situations and optimization of strategies of protective and rehabilitation measures are being developed for approval. These developments are using the results from the EU/CIS cooperative research projects (ECPs and JSPs). The new recommendations are expected to be finalized in 1996.

4.3 Intervention criteria in Belarus

In the first years after the Chernobyl accident the Byelorussian regulation followed that of the All-Union (USSR). Starting from 1990-91 the basic documents that regulate the use of countermeasures in the Republic of Belarus are the following:

(1) Republican concept of living in the territories contaminated with radionuclides as a result of the Chernobyl Nuclear Power Plant catastrophe, adopted by the Bureau of the Presidium of the Byelorussian Academy of Sciences of 19 December, 1990;

(2) Concept of residing the population in the regions affected by the Chernobyl Nuclear Power Plant catastrophe, adopted by the USSR Government of 8 April, 1991, N164.

The essence of the second concept is that two levels of annual individual effective doses of "Chernobyl origin" were established for introduction of countermeasures:

- when annual individual effective doses do not exceed 1 mSv no interventions should be made;
- when annual individual effective doses fall in the range of 1-5 mSv a complex of protective measures should be used aimed at constantly reducing the dose rate;

- when annual individual effective doses exceed 5 mSv resettlement should be implemented.

At present, Byelorussian scientists develop a concept of protective measures in a rehabilitation period for the population living in territories of the Republic of Belarus affected by the Chernobyl accident. This concept is at the stage of adoption.

According to the concept, in territories where the annual individual effective doses do not exceed 1 mSv, living conditions and economic activities should not be limited by radiation protection factors. Consequently, additional exposure of the population due to radioactive fall-out resulting in annual individual effective doses lower than 1 mSv is permissible and should not require any limitations (Article 3 of the law *On Social Protection of Citizens Affected by the Chernobyl Nuclear Power Plant Catastrophe*). Monitoring of objects in the natural environment and of agricultural production should be carried out to calculate and estimate real radiation doses to the population and to implement, if needed, limited and local protection measures.

In territories where annual individual effective doses exceed 1 mSv but are lower than 5 mSv, well-grounded activities aimed at further reduction of individual and collective doses should be implemented. These measure would include, in addition to radiation monitoring of the natural environment and of agricultural production, local decontamination of sites where the external exposure is the dominating exposure pathway.

In territories where the annual individual effective doses exceed 5 mSv, residing would not be recommended and economic activities would be limited.

According to the Republican concept the level of 5 mSv/y from the Chernobyl accident should constantly be reduced. The reduction rate were defined as:

1990	5 mSv/y
1993	3 mSv/y
1995	2 mSv/y
1998	1 mSv/y

The above mentioned concepts have been used as basis of the law of the Republic of Belarus On Social Protection of the Citizens Affected by the Chernobyl Nuclear Power Plant Catastrophe.

4.4 Evolution of intervention criteria in Ukraine

The Ukrainian strategy for setting criteria in terms of intervention levels for countermeasures on the radioactive contaminated territories in Ukraine has been changing during all the years following the Chernobyl accident. In the years 1986-1989, the USSR criteria formed the basis for protective measures in Ukraine.

In 1989-1991 the “two-tier-lifetime-dose concept” for decision making was considered in Ukraine. Two lifetime dose levels over 70 years of 70 mSv and 150 mSv were suggested as intervention levels. This concept has not been applied in Ukraine.

In 1991 the so-called “three-tier-annual-dose concept for intervention was proposed in Ukraine. In accordance to this concept the annual dose for decision making in certain settlements was to be the sum of the external γ-dose from deposited activity, the internal dose from ingestion of locally grown contaminated foodstuffs containing ^{137}Cs and ^{90}Sr, and the inhalation dose from resuspension of plutonium.

This “three-tier-annual-dose concept” for intervention has been used in Ukraine up until 1995. The intervention levels were 1 mSv/y and 5 mSv/y and since

1994 also 0.5 mSv/y. In accordance to these levels all contaminated territories in Ukraine were divided in zones. Different sets of countermeasures, monetary compensations and privileges were introduced in each zone. The radiological control were provided in the territories where the annual doses were 0.5-1 mSv. The complex of protective actions were to be taken in territories where the annual doses were in the range 1-5 mSv. In territories where the annual doses exceeded 5 mSv relocation (resettlement) were to be considered.

The evolution of the Ukrainian criteria is shown in Fig. 9.

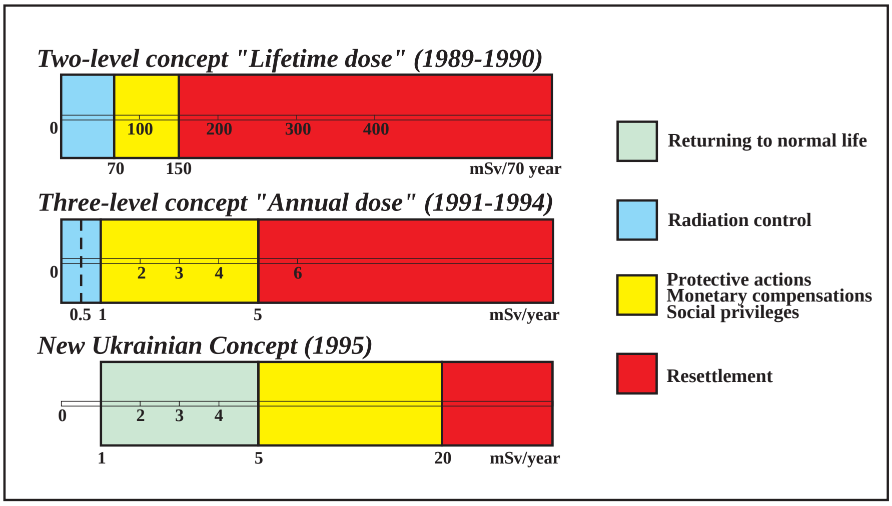

Figure 9. Evolution of Ukrainian criteria for countermeasures during the years 1991-1995.

At present, in the large part of the affected territory of Ukraine the annual doses do not exceed 1 mSv. This level of dose is identical to the dose limit for exposure of the population in practices used in many countries including Ukraine. However, because the exposure from the Chernobyl accident and the exposure from non-accidental sources were considered separately, the social security of inhabitants receiving the same doses depends on the origin of the source giving rise to the exposure.

Taking into account this curiosity the possibility of a new concept of intervention level in territories contaminated by the Chernobyl accident are now considered. The main peculiarities of this new concept are the following:

- changing the dose levels for territory zones;
- changing both the concept of annual dose and the methodology of annual dose calculation for dividing into zones.

It is proposed to determine the annual dose for intervention as the sum of accidental doses (from all Chernobyl exposure pathways) and industrial exposure (practices).

Annual dose levels of 1, 5 and 20 mSv are considered as intervention levels for the whole Ukrainian territory. The protective actions related to these levels are:

- no special protective actions have to be implemented if the annual dose in settlements is below 1 mSv;
- radiological control has to be provided in territories where the annual doses are in the range of 1-5 mSv; effective protective actions should be introduced for the settlements where the annual doses are in the range of 5-20 mSv;

- the possibility of resettlement must be considered if the annual doses exceed 20 mSv.

Such type of guidance for interventions is a compromise and, in some sense, a composition of practice and intervention criteria for the late phase of the Chernobyl accident. Therefore, the realization of this guidance is possible only if the additional accidental exposure is comparable to the exposure from normal practices for most of the territories.

If the society is ready to set up these dose levels for the population living around nuclear power plants, the value of these dose levels for the Chernobyl contaminated territories have to be decreased with the fraction due to Chernobyl in the late phase.

This concept has been revised and already accepted not only by single scientists but also by the National Commission of Radiation Protection of Ukraine, the health Ministry, the Ministry of Chernobyl and the Council of Ministry. At present, it is under consideration by the Supreme Soviet of Ukraine.

4.5 Evolution of international guidance

Over the past decade considerable progress has been made in developing internationally recognized principles for decisions on protective measures following accidents involving radioactive material, and in providing quantitative guidance for applying these principles, notably by the International Commission on Radiological Protection (ICRP), the IAEA, the World Health Organization (WHO), the Food and Agriculture Organization of the United Nations (FAO), the Commission of the European Communities (CEC) and the Nuclear Energy Agency of the Organisation for Economic Cooperation and Development (OECD/NEA).

Following the accident at Chernobyl, it became evident that some clarification of the basic principles for intervention was necessary. In particular, it became clear from the experience of the Chernobyl accident recovery that there was a need for a simple set of internally consistent intervention levels that could have some generic application internationally. Such a set of values was considered desirable to increase public confidence in authorities charged with dealing with the aftermath of an accident.

4.5.1 International Guidance at the time of the Chernobyl Accident

The Commission of the European Communities (CEC) was the first international body to publish guidance in 1982 to its member states on reference levels of radiation dose as guidance to national authorities in setting intervention levels. Similar guidance was published by the ICRP in 1984 [25], World Health Organization, WHO, and the International Atomic Energy Agency, IAEA.

The guidance given by these four organizations was similar in essence. The WHO guidance was less quantitative; the reference dose levels for sheltering, distribution of stable iodine tablets, and evacuation set forth by CEC differ slightly from those given by ICRP and IAEA; and the CEC did not give any values for control of foodstuffs. The ICRP and IAEA gave almost identical advice.

The basic principles given by ICRP [25] for planning intervention for accident situations and setting intervention levels were the following:

(a) Serious deterministic effects should be avoided by the introduction of countermeasures to limit individual dose to levels below the thresholds for these effects;

(b) The risk from stochastic effects should be limited by introducing countermeasures which achieve a positive net benefit to the individuals involved;

(c) The overall incidence of stochastic effects should be limited, as far as reasonably practicable, by reducing the collective dose equivalent.

It was internationally recognized that the spectrum of accident situations is wide, and that difficulties in implementing protective measures after an accident vary widely from country to country and even from place to place within a country. Therefore, it was not considered possible to set one generally applicable intervention level at which a particular action would always be required.

On the other hand, it was recognized that introduction of protective measures would be almost certain if the projected radiation dose were such that serious deterministic effects or a high probability of stochastic effects would be expected. It was also considered that it would be possible, on radiation protection grounds, to define a level of radiation dose for each countermeasure below which introduction of the countermeasure would not likely be warranted.

The numerical values of the intervention levels recommended by ICRP [25] for the first year after the accident are summarised in Table 12.

Upper dose levels above which introduction of the countermeasure is almost certain and lower dose levels, below which introduction of the countermeasure is not warranted were given for whole body irradiation and also for individual organs. Between the recommended upper and lower levels site-specific intervention levels were expected to be set by national authorities. The intervention levels covered both early and intermediate phases. For the late phase no values were recommended, since it was considered that the main questions facing the decision maker would be whether and when normal living could be resumed, and the situations would vary too widely to give any generic numbers for that purpose.

Table 12. ICRP intervention level ranges for introducing countermeasures.

Dose levels for intervention		
Protective measure	Whole body	Single organs
Sheltering	5 - 50 mSv	50 - 500 mSv
Stable iodine	-	50 - 500 mSv
Evacuation	50 - 500 mSv	500 - 5000 mSv
Relocation	50 - 500 mSv/a	not anticipated
Control of foodstuffs	5 - 50 mSv/a	50 - 500 mSv/a

The projected dose per year for relocation and foodstuff control are defined only for the first year.

In regard to international guidance on intervention levels a number of problems were identified when it was applied to the Chernobyl accident, although its basic principles were still considered to be valid. The major difficulties in its application were:

- how to apply the intervention levels; for example, in the case of food, did the intervention level refer to the sum of the food items or to each foodstuff separately?
- how to compare the dose with the intervention level; was the projected dose or the avertable dose relevant?
- how was the principle (c) to be applied? what was the relationship between principles (b) and (c)?

Major confusion was also created by the references in the ICRP Publication 40 [25] to the dose limits in justifying the numerical values of the intervention levels.

The radiation protection philosophy of today distinguishes between the introduction of a practice which causes either actual exposures or probabilities of exposure and therefore will add radiation doses to the existing background, and intervention in existing (de-facto) situations involving radiation exposures, with the aim to decrease or subtract such exposures.

4.5.2 ICRP Publication 63

ICRP Publication 63 [29] updates and extends ICRP Publication 40 and includes quantitative guidance on intervention levels. This guidance covers the introduction of such protective actions over very short times, their introduction and continuation following periodic review over protracted timescales lasting perhaps years and intervention over larger areas. All accidents are different, as are the approaches of national organizations having responsibility for response to an accident. It is the intention of ICRP that the general guidelines in Publication 63 should be translated into appropriate emergency response plans by competent national authorities.

Publication 63 establishes for each protective action an almost always justified intervention level which is defined as the level of avertable dose above which it is likely that intervention is almost always justified. In addition, the publication recommends that the optimized intervention level that would be achievable in practice depending on the accidental and site specific circumstances is likely to be no more than a factor of ten below the almost always justified value. The recommended intervention levels in Publication 63 are given in Table 13 [29].

Table 13. Recommended intervention levels from ICRP in Publication 63 for sheltering, evacuation, iodine prophylaxis, relocation and foodstuff restrictions.

Intervention levels of avertable dose or avertable activity concentration		
Protective measure	Almost always justified (mSv)	Range of optimized values (mSv)
Sheltering (less than 1 day)	$50^{(a)}$	$5\text{-}50^{(a)}$
Iodine prophylaxis	$500^{(b)}$	$50\text{-}500^{(b)}$
Evacuation (less than 1 week)	$500^{(a)}$ $5{,}000^{(c)}$	$50\text{-}500^{(a)}$ $500\text{-}5{,}000^{(c)}$
Relocation	$1{,}000^{(a)}$	5-15 mSv·month^{-1} $^{(a)}$
Restriction on a single foodstuff	10 mSv in a year$^{(d)}$	1-10 kBq·kg^{-1} (β) 10-100 Bq·kg^{-1} (α)

(a) Level of avertable effective dose.
(b) Level of avertable equivalent dose to thyroid.
(c) Level of avertable equivalent dose to skin.
(d) Level of avertable effective dose committed in a year.

4.5.3 IAEA Safety Series No. 109

Following the Chernobyl accident, it became evident that some clarification of the basic principles for intervention was necessary, as well as more internationally recognized numerical guidance. Because of the need to have international consensus on the values of these generic intervention levels, an Advisory Group developed proposals that were published in a Technical Document (IAEA-TECDOC-698) in April 1993, entitled *Generic Intervention Levels for Protecting the Public in the Event of a Nuclear Accident or Radiological Emergency.* This interim report was circulated to all Member States of the IAEA and to other organisations for comments.

In September 1993, the IAEA convened a Technical Committee on Intervention after Accidents, which modified the text and values proposed in the TECDOC-698, taking account of the many comments received from Member States and international organisations and combined them with the draft revision of Safety Series No. 72. The result of this work is a Safety Guide, that represents the international consensus reached on principles for intervention and numerical values for Generic Intervention Levels. The Safety Guide has been published as Safety Series No. 109 [21]. The generic intervention levels for urgent and longer term protective actions are given in Table 14.

Table 14. Generic intervention levels for sheltering, evacuation, iodine prophylaxis, temporary relocation and permanent resettlement from IAEA Safety Series No. 109.

Protective measure	Generic optimized intervention level (*avertable dose*[(a)] by the countermeasure)
Sheltering (less than 1 day)	10[(b)]
Evacuation (less than 1 week)	50 mSv[(c)]
Iodine prophylaxis	100 mGy due to radioiodine[(d)]
Temporary relocation	Initiate at 30 mSv in a month; suspend at 10 mSv in a month
Permanent relocation	If lifetime dose would exceed 1 Sv or if relocation time would exceed 1-2 years

(a) Sum of external and committed internal effective dose, unless noted.

(b) This generic level has been optimized for the maximum anticipated period of sheltering (2 days). Authorities may advise sheltering at lower intervention levels for shorter periods, or to facilitate further protective actions, *eg*, evacuation.

(c) This generic level has been optimized for the maximum anticipated period of evacuation (7 days). Authorities may initiate evacuation at lower intervention levels for shorter periods and also where evacuation can be carried out quickly and easily, *eg*, for small groups of people. Higher intervention levels may be appropriate in situations where evacuation would be difficult, *eg*, for large populations or in the case of inadequate transportation.

(d) Committed dose to the thyroid.

Control of food and water may have to be considered under three different circumstances: where alternative supplies are available; where alternative supplies are scarce; and for distribution in international trade.

Intervention levels specifically for the withdrawal and substitution of foodstuffs can be developed according to the principles of justification and optimization. Where alternative food supplies are readily available, the requirement that intervention be justified is easily satisfied. It is, however, important in the process of optimization that consideration be given to other measures that could reduce levels of food contamination still further. Some agricultural countermeasures do exist that can be assumed generally feasible, such as transferring animals to stored feed. These kinds of countermeasures are often highly cost-effective. The numerical values of the levels emerging from optimization of agricultural countermeasures (action levels) are almost always lower than the levels (intervention levels) developed on the basis of withdrawing and substituting foodstuffs alone.

The generic action levels for use by national authorities when alternative supplies of food are available are given in Table 15.

Table 15. Generic Action Levels for foodstuffs from IAEA Safety Series No. 109.

<table>
<tr><th colspan="3">Action levels for foodstuff countermeasures (kBq·kg^{-1})</th></tr>
<tr><th>Radionuclides</th><th>Foods destined for general consumption</th><th>Milk, infant foods and drinking water</th></tr>
<tr><td>^{134,137}Cs, ^{103,106}Ru, ^{89}Sr</td><td rowspan="2">1</td><td>1</td></tr>
<tr><td>^{131}I</td><td rowspan="2">0.1</td></tr>
<tr><td>^{90}Sr</td><td>0.1</td></tr>
<tr><td>^{241}Am, ^{238,239}Pu</td><td>0.01</td><td>0.001</td></tr>
</table>

In situations where extensive restrictions on food supplies could result in nutritional deficiencies or, in the extreme, starvation, case-by-case evaluations will be required. The intervention levels that would emerge from an optimization in the situation where alternative supplies are scarce would be similar to the values recommended by the ICRP in Table 13. For example, for β-emitters like $^{134+137}$Cs and ^{131}I in milk and vegetables, the optimized intervention level for withdrawal and substitution would be about one to about ten kBq/kg. For meat and milk products, the corresponding intervention levels would be about ten to about a hundred kBq/kg.

The guidance given by IAEA in the Safety Series No. 109 [21] and shown in Tables 14 and 15 have all been used in the Basic Safety Standards from six international organisations [20].

4.6 CIS-guidance compared with international guidance

According to the international guidance from ICRP and IAEA intervention levels refer to the dose that is expected to be averted (avertable dose) by a specific countermeasure over the period it is in effect. If an intervention level (IL) is exceeded, *i.e.*, if the expected avertable individual dose is greater than the intervention level, then it is indicated that the specific protective action is likely to be appropriate for that situation. Intervention levels are specific to accident situations.

Operational intervention levels (OIL) are derived from the intervention level (IL) of avertable dose for *specific* countermeasures through site and accident specific parameters. Operational intervention levels can be given in any quantity, *eg*, dose rate or activity concentration. If the relevant quantity is foreseen to exceed the OIL in a time period for which the IL has been derived, the specific countermeasure should be introduced.

Action levels (AL) refer to *different* protective measures or *strategies* of protective measures like agricultural countermeasures or radon reducing measures in houses. Action levels relate to the residual dose without any remedial actions taken, *i.e.*, action is taken when the relevant quantity exceeds the action level.

The intervention guidance used in the CIS republics have the character of action levels expressed as doses above which different protective actions would be needed. For a given exposure situation there would be a fixed ratio of avertable dose to action level. An action level for resettlement of, say 20 mSv/y, would be equivalent to an avertable lifetime dose of 150-300 mSv over the following 70 years if the effective environmental half-life is 5-10 years.

CIS intervention/action levels are thus another way to express avertable doses, and, conceptually, they are in line with the principles recommended by the international organizations. However, the numerical values differ somewhat from the international numerical guidance with a tendency of CIS-levels being lower than the international numerical guidance. Also, there are differences between the national guidance in Russia, Ukraine and Belarus.

5 Discussion and Conclusions

Decisions on countermeasures include factors describing benefits from the countermeasure and those describing harm. In analyzing the inputs to the decision, it is necessary to decide on the relative importance of each factor. These judgements have to be made irrespective of the decision aiding technique used. The resultant decision will be the same provided that the database is the same and the judgements are consistent.

There has been essentially a broad acceptance internationally of the principles for intervention. However, it has not been possible to reach agreement for the purpose of defining a net benefit, on the exact weighting to be attached to each of the factors influencing the decision to take a protective action. In any case, the importance of some of the factors will vary with the site and nature of the accident, thus making it difficult to generalize. The dominant factors are those related to radiological protection principles, and to psychological and political factors.

An important aim of protective actions is to reduce the likely numbers of cancers as much and as effectively as reasonably possible. It seems reasonable that a national authority should place at least as much effort and resources into avoiding a radiation induced cancer as it does into avoiding cancers from other causes. If intervention levels have been set to achieve this, it can be seen that choosing lower levels would mean allocating more effort and resources to radiation protection than to other means of health protection, and setting higher levels would mean allocating less effort and fewer resources to radiation protection.

The residual individual risk of stochastic effects after protective measures have been taken is often a significant concern to national authorities. Such individual risk considerations can be directly incorporated into the setting of intervention levels. Alternatively, the national authority can decide to adopt explicit objectives for individual risk levels whereby they would undertake intervention, if it is justified, to keep risks of effects below these levels. The basis for setting such objectives for individual risk levels for intervention would be different from that for deriving dose limits for practices.

Most intervention is disruptive to normal social and economic life. Change may cause anxiety, which can be harmful to health and well-being. However, the absence of protective measures can also cause anxiety, which is often exacerbated by a lack of objective information. These effects are non-radiological, are not easily quantifiable, will vary markedly between countries, and in any case will normally have opposing influences on the choice of intervention levels. These considerations complicate decisions on intervention, which should generally involve other persons as well as radiation protection specialists.

The basic principles for radiological protection in intervention situations after nuclear or radiological accidents are based on the concepts of optimized intervention levels of avertable dose for specific countermeasures to mitigate the consequences of the accident. These principles are generally clear and logical but they need to be detailed explained in every post-accident situation [6] and [37].

Being necessary and sufficient in the earlier phases of an accidental situation they meet obstacles in their realization in the later phases of the post-accident situation. Especially non-radiological protection factors (*eg* psychological factors) need to be addressed in order to make an optimized overall health protection of the affected population. The inclusion of non-radiological protection factors in an overall optimization of health protection after an accident is a discipline for *decision maker(s)* with guidance from radiation protection experts as well as experts in the fields of social and psychological sciences. Post-accident management is therefore not a radiological protection problem only.

The socio-psychological factors are important and they may even be the dominating ones. Social-psychological countermeasures are a new category of action, in the sense that social protection philosophy has not yet been developed to fully include their application after a nuclear accident. From the experience in CIS following the Chernobyl accident, the need for social-psychological countermeasures was obvious.

To achieve optimized countermeasure strategies public understanding and support is needed. It is crucial to have a complete understanding of the protective measures in the affected population to achieve a maximum effect of the introduced countermeasures. If this is sacrificed for political conjuncture it may lead to serious complications in the future. A detailed legislation and regulation basis is thus very important for post-accident management. It gives a solid base for assured actions to all participating bodies. New regulation being introduced after an accident may create social distortion and distrust to the responsible authorities as was experienced in the former USSR after the Chernobyl accident.

Time scale is another important factor. Transition from post-accident period to normal life is complicated due to socio-psychological difficulty to accept residual effects. It is very important for public understanding and acceptance that the end of the post-accident phase is clearly defined as being “normal”, even if the radiological situation is different from the pre-accident situation. Natural variations (regional, global) of “normal” situations could here be used as terms of reference.

The basic intervention philosophy in the three republics have been under constant evolution since the Chernobyl accident. At present, the different concepts being developed include - in addition to radiation protection factors - social protection considerations. The development also includes a suggestion to unify the systems of radiation protection for interventions and practices.

In **Russia**, new basic recommendations applicable to the existing contaminated territories and possible future accidental situations are being developed to include all experience on liquidation of the consequences of nuclear accidents and nuclear weapons tests. The guidance will be based on both radiation and non-radiation risks and will be expressed in intervention levels in terms of *General Intervention Levels (projected doses)* establishing strategies of intervention, *Specified Intervention Levels (avertable doses or risks)* for radiation protection purposes, and *Specified Intervention Levels* (residual doses or risks) for social protection purposes.

In **Ukraine**, annual dose levels of 1, 5 and 20 mSv are considered as the international levels for the whole Ukrainian territory. The protective actions related to these three levels are *no special protective actions* below 1 mSv, *radiological control* in territories where the annual doses are 1-5 mSv, *effective protective actions* where the annual doses are in the range of 5-20 mSv, and the *possibility of resettlement* if the annual doses would exceed 20 mSv.

In **Belarus**, a concept of protective measures is being developed. According to this concept, living conditions and economic activities should *not be limited* in territories where the annual individual effective doses are less than 1 mSv. In territories where annual doses exceed 1 mSv but are lower than 5 mSv, well-grounded activities aimed at further reduction of individual and collective doses should be implemented. In territories where the annual individual effective doses exceed 5 mSv, residing would not be recommended and economic activities would be limited.

CIS intervention/action levels as being developed are conceptually in line with the principles recommended by the international organizations However, the numerical CIS-levels being somewhat lower than the international numerical guidance. Also, there are differences between the national guidance in Russia, Ukraine and Belarus. Harmonization of intervention levels would be of utmost importance in the context of gaining public confidence.

The effect of different countermeasures and the radiological consequences of living in contaminated areas can be expressed in terms of *avertable risk* and *residual risk*, both at the individual and the collective level. This way of communicating the overall situation might be a more direct and understandable way than using radiological quantities. The development of methodology on risk analysis and risk communication in the framework of intervention should therefore have a high priority.

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A Risk assessment methodology and its application to accidental situations

Vladimir F. Demin

A.1 Needs in Risk Assessment

The decisions on the introduction of post-accident off-site protection and restoration measures can be made with allowance for only radiological consequences using the so-called dose approach.

Regulatory documents adopted by international and national organizations, *eg*, [5], [14], [21], [28], [29], [39] and [45], respectively, at different times, including the recent years, institute dose intervention levels.

The radiation doses to the population are determined by direct measurements or calculated. Comparing the estimated doses with the dose intervention levels, decisions on the radiation or social protection can be made.

In this case and for assessment of radiation accident consequences the concept of the effective dose, E, is often used first of all in the practice in the former Soviet Union and CIS after the Chernobyl accident.

This concept was developed and suggested by ICRP in 1977 [22]. Later it was developed and refined in ICRP Publication 60 [28].

As it follows from the experience in the assessment and analysis of the consequences of nuclear accidents or nuclear weapon tests as well as in the implementation of the protection and restoration measures, there are some reasons, on the one hand, to go beyond the scope of the radiation protection and to include non-radiation risks as well. On the other hand, remaining in the framework of the radiation protection, it is not enough to base oneself on the concept of the effective dose, even though only the stochastic effects due to the exposure are considered.

A.1.1 Using the concept of effective dose

The effective dose, E, is actually a risk index. The weighting (by different organs of the human body) factors that determine the effective dose are calculated from the values of the radiological risk. The change-over from E to the values of risk is performed, if necessary, by simple multiplication of E by the corresponding risk coefficients.

However, there are some features of the effective dose which limit its use in the case under consideration (nuclear accidents and nuclear weapon tests). The value of risk determined by E is:

- integrated over the whole duration of the radiobiological stochastic effect after an exposure (tens of years for carcinogenesis and all generations to come for genetic consequences of the exposure);
- averaged over the time period at exposure and over the population of different countries.

As a result, assessment of the radiological health consequences based on effective dose, E, does not involve the time factor. No data on the radiological risk can be obtained for the different intervals of time after a nuclear accident or test. The effective dose does not distinguish a great difference in time between the occurrences of leukaemia and some “solid” cancers (see below). Besides, the value of E cannot make allowance for the local and age features of population cohorts (or personnel) for which the late radiation induced health effects are estimated.

All these points are the critics of non-proper use of the effective dose but not the concept itself. One should note that the effective dose was developed and recommended mainly for use in radiation protection in normal conditions (practices).

A.1.2 Non-radiation risks

The necessity of estimating non-radiation risks is due to the following:

- some countermeasures being implemented can have detrimental side consequences of a non-radiological nature for a population; for example, the relocation, as follows from the experience available, may adversely affect the human health because of changing the social and other living conditions;
- note the effect of so-called competition of risks; this effect results essentially in the mutual influence of different risk factors even though initially they are statistically independent;
- some possible problems with the health of the population caused by local or national-wide social living conditions requires, in the context of the most efficient use of resources in health protection, an assessment in a unified way - through a risk analysis - the state of health as a whole and the background radiation and non-radiation risk factors;
- taking into account the acute, at all times, need for the socio-psychological substantiation of the countermeasures (interaction with the local population, authorities and mass media), a substantiated scientific-methodical basis must be available to perform the comparative assessments and analysis of various risks;
- as follows from the present-day methodology of estimating the radiological risk, the background values of carcinogenic risk must be known for the application of this methodology (models of relative risk).

A.1.3 Recent developments

As can be seen from the points listed above, assessment of consequences of nuclear accidents or tests and decision making on mitigating their health risks, requires methods on risk assessments from various radiation and non-radiation risk sources to be developed and used. This is one of the lessons learned from the Chernobyl accident.

Understanding of these necessities increases in CIS and among the participants of the JSP 2. In Russia some steps have already been taken in the development of the respective scientific basis and regulation. In 1995 the new regulation document was developed for social protection of the population of the Altai region using the recommendations from the risk assessments [13]

In the frame of the Belarus and Russia state research program (Chernobyl and Altai case studies) and the international (EU-CIS) project JSP 2 the research sub-project "developing the methodology (MAR) and data bank (BARD) on risk analysis" started in 1994. The first version of MAR was published in [11].

The main functions of BARD [5] are:

- assessment of the radiological and non-radiological consequences of nuclear tests and accidents,
- assessment of the health of a population in terms of risk indices,
- analysis of effectiveness of radiation and social protection measures.

In addition, BARD can also be used for other tasks related to risk analysis. One version of BARD is developed as a module for a decision aiding computer system for a post-accident management. BARD includes:

- service and calculation codes realizing the methodology mentioned,
- health-demographic data which are necessary for radiological and non-radiological risks assessment.

BARD is to a certain extent similar to the computer codes ASQRAD [2] and SPIDER [38] developed by CEPN (France) and NRPB (UK). BARD differs from the latter two by the large intrinsic health demographical data (HDD) base, the possibility of calculating non-radiological risks, some areas of application etc.

One should note that in Russia the additional development of regulation documents for post-accident activities based on risk assessment results began in 1995.

In this part of the report only the methodology of risk analysis is considered.

A.2 General methodology

In risk analysis and medical demography many different basic and derivative risk indices and quantities are used, depending on the concrete task.

Here a qualitative and quantitative definitions are given for some risk indices, which are essential in the applications considered. There are many publications concerning the methodology of risk and medical demography analysis, *eg*, [7], [8], [26], [28], [33] and [42].

First of all the basic (fundamental) quantities in risk or health demography analysis are defined. They are the age-specific death rate, the survival function and the life expectancy.

A.2.1 Basic quantities

Age-specific death rate. The age-specific death rate, $m(a)$, is defined as the probability density (or probability per unit of time) for death at age a for a person, who is alive up to the age a. This quantity has some other names including the conditional risk rate, the force of mortality or simply the mortality rate. If $m(a)$ refers to death from a specific cause i it is named the age-cause-specific death rate and denoted as $m_i(a)$.

Survival function. The survival function $H(a)$ is defined as the probability that an individual would reach the age a (beginning from the birth) and calculated by the formula:

$$H(a) = \exp\left(-\int_0^a m(a')\,\mathrm{d}a'\right) \tag{A.1}$$

For a person of age a, the probability, $H(a,\, t)$, of being alive t years more can be calculated as:

$$H(a,\, t) = \frac{H(a+t)}{H(a)} \tag{A.2}$$

Life expectancy The total life expectancy T (from the birth) is calculated as:

$$T = \int_0^\infty H(t)\,\mathrm{d}t. \tag{A.3}$$

Similarly the life expectancy $T(a)$ for a person with age a is:

$$T(a) = \int_0^\infty H(a,\, t')\,\mathrm{d}t', \tag{A.4}$$

Note that $T = T(0)$ and $T(a) > T - a$. It is not unusual to meet the simplified, incorrect notion that $T(a) = T - a$.

A.2.2 Risk indices

Lifetime risk. The lifetime risk R_i is defined as a probability of death from the ith death cause (or in other words the risk source) during the whole future life and calculated by the formula:

$$R_i = \int_0^\infty H(t) m_i(t)\,\mathrm{d}t, \tag{A.5}$$

where $H(t)$ and $m_i(t)$ are defined above. Note that the normalization condition:

$$\sum_i R_i = 1 \tag{A.6}$$

(with the summation over all death causes) can be used in the calculation to prove its accuracy.

The lifetime risk, $R_i(a)$, for a person at age a can be calculated similarly:

$$R_i = \int_0^\infty H(a,\, t')\, m_i(a + t')\,\mathrm{d}t' \tag{A.7}$$

Death risk rate $r_i(a,\, t)$ for a person at age a as a function of time t is given as:

$$r_i(a, t) = H(a,\, t)\, m_i(a + t) \tag{A.8}$$

The quantities m_i and r_i are often called the conditional and the unconditional risk rates (or probability densities), respectively.

In general $m_i(t)$ can depend on other parameters. It will be specified under consideration of concrete tasks and death causes.

Similarly to Eq. (A.7) and Eq. (A.8) a lifetime disease risk $Rd_i(a)$ and disease risk rate $rd_i(a,\, t)$ can be defined as:

$$rd_i(a, t) = H(a,\, t)\, md_i(a + t) \tag{A.9}$$

where $md_i(a)$ is the age-cause-specific disease rate. The value of $Rd_i(a)$ can obviously be greater than 1.

Detriment to human health. The detriment G_i to human health due to some ith death cause is defined as a loss of life expectancy in man-years (or man-days) caused by the action of the given source and calculated by:

$$G_i = \int_0^\infty \Big(H^{(i)}(a) - H(a) \Big)\,\mathrm{d}a, \tag{A.10}$$

where:

- $H(a)$ is the total survival function,
- $H^{(i)}(a)$ is the survival function in the absence of the ith death cause.

Taking into account that:

$$H(a) = H^{(i)}(a) \cdot H_i(a), \tag{A.11}$$

where $H_i(a)$ is the survival function under the action of the ith source alone, Eq. (A.9) can be rewritten as follows:

$$G_i = \int_0^\infty H^{(i)}(a) \cdot \tilde{H}_i(a)\,\mathrm{d}a, \tag{A.12}$$

$\tilde{H}_i(a) = 1 - H_i(a)$ is the probability of dying at the age a from the action of the ith death cause alone.

For a person having reached the age e, the detriment $G_i(e)$ is calculated through the functions $H(e,\, a)$ and $H^{(i)}(e,\, a)$:

$$G_i(e) = \int_e^\infty \Big(H^{(i)}(e,\, a) - H(e,\, a) \Big)\,\mathrm{d}a. \tag{A.13}$$

It is useful to define $G_i(e)$ equivalent to the above definition:

$$G_i(e) = \int_e^{\infty} r_i(e, a)\, T(a)\, \mathrm{d}a \tag{A.14}$$

where $T(a)$ is defined above (life expectancy at age a). A similar formula can be written for detriment caused by morbidity:

$$Gd_i(e) = \int_e^{\infty} rd_i(e,\, a)\, Td_i\, \mathrm{d}a \tag{A.15}$$

Here $Gd_i(e)$ is the mathematical expectation of the duration of diseases caused by a risk source i during all life time after age e, and $Td_i(a)$ is the average duration of a disease at age a.

A.2.3 Risk indices on the population level

Above, the main risk indices referred to one person are defined. Usually they are named individual risk indices. Taking into account the probabilistic (stochastic) nature of risk it would be reasonable to call them risk indices on the cohort level when a cohort of people with definite descriptions (on an age, sex, local conditions etc.) is considered.

Here formulas for the risk indices on the population level are given. They are derivative from the main indices considered above. Let a population with an age composition described by an age distribution density be $n(a)$. The total amount of people, N, in this population is then equal to:

$$N = \int_0^{\infty} n(a)\, \mathrm{d}a. \tag{A.16}$$

The death rate on the population level or in other words an annual mortality $\dot{M}_i(t)$ from an i-th risk source is then calculated as follows:

$$\dot{M}_i(t) = \int_0^{\infty} n(a) r_i(a,\, t)\, \mathrm{d}a. \tag{A.17}$$

If the integration is for a limited time interval, *eg*, from a_1 to $a_1 + \Delta a$, the mortality for an separate age group can be calculated as:

$$\dot{M}_i(a_1,\, \Delta a,\, t) = \int_{a_1}^{a_1+\Delta a} n(a) r_i(a,\, t)\, \mathrm{d}a. \tag{A.18}$$

The total number M_i of excess death cases due to a risk source considered is given by:

$$M_i = \int_0^{\infty} \dot{M}(t)\, \mathrm{d}t. \tag{A.19}$$

On the population level the so-called standardized death indices m_i^s are often used. They are defined in the following way:

$$m_i^s = \int_0^{\infty} n^s(a) m_i(a)\, \mathrm{d}a, \tag{A.20}$$

where $n^s(a)$ is an age distribution density for the standard population.

More details about this and other risk indices used in the medical demography can be found, *eg*, in [33]. As a rule, all risk indices on the population level are normalized to 100,000 people, *i.e.* the quantity $\dot{M}_i(t)$ from Eq. (A.14) should in this case be multiplied by $100,000/N$.

A.2.4 Basic data

As can be seen from the above definitions and formulas, to assess risk in different indices it is necessary to know initial age-specific mortality rates for a cohort under consideration, or, in other words, "background" **h**ealth-**d**emographical **d**ata (HDD, see above the functions $m(t)$ and $m_i(t)$). The term basic, or "background", is related to the state of the health of the population before (or without allowance for) the action of an additional death cause under consideration.

HDD should include additionally to the functions m and m_i values of the age density distribution for populations considered. The HDD represent a basic body of initial data for risk assessment. Depending on the application the basic data must be known in specified details.

The overall values of $m(t)$, *i.e.* the sum of all background death causes, must always be known. It is enough in some cases. To assess the radiological risk using the present-day approach the background values of HDD for malignant tumors of different localization must be additionally available. Bearing in mind the main application of the techniques developed in this work and the BARD, namely, the population in the territories suffered from nuclear accidents or nuclear weapon tests, it is necessary to know the HDD for respective populations in different years.

Two types of HDD are distinguished: current and cohort (HDD of a real generation) one's. HDD of the first type are used as a rule in the risk analysis. They are derived on the basis of one-time cross-section of age specific mortality data [33]. Indeed, such HDD have been prepared in the data base of BARD. Consequently it is assumed that during all time intervals in which the risk analysis is made HDD do not change essentially. In the areas of BARD applications this is not strictly so, and changing the current HDD by cohort one's or some modification of the former should be additionally studied.

In many HDD all mortality for ages after 85 (or sometimes 75) years are combined in one group with a constant value of age specific mortality coefficients. For some tasks more realistic HDD for large ages would be desirable. Observation of the methods of a reasonable interpolation of HDD to ages $a > 85$ (or 75) years can be found, *eg*, in [33].

A.2.5 Risk competition

The values of the respective risk indices for two or several independent death causes are usually considered in the simplified approach of risk assessment to be simply summed to yield the overall effect (the additive property). This property seems usually to be evident and have no need of any proofs.

The risk indices R and G are not, in fact, additive, no matter whether the death causes considered are dependent or independent. The risks can be summed only in the case when they are low with appropriate assumptions under proper conditions. A man dies only once. This manifests itself in the fact that the total lifetime risk is equal to unity (see Eq. (A.6)). A change in one of the death causes automatically leads to a change (renormalization) in the lifetime risk indices of other sources in action, even though they are statistically independent. Consider some two independent death causes characterizing the respective lifetime risks R_1 and R_2. If one of these (R_1) is reduced, the other (R_2) would increase and vice versa. Similar changes would occur in the detriment indices G_1 and G_2. The term "risk competition" is sometimes used to describe this property.

It can also be seen qualitatively from the corresponding formulas for the risk indices R and G. The same can be easily demonstrated by referring directly to the BARD.

A.2.6 Mortality and morbidity

The mortality alone was considered in all the quantitative definitions of risk indices above. It is clear that morbidity must be taken into account for a complete assessment of risk. This issue has not been considered at the given stage of work. Only simple formulas are given above, others can be found, *eg*, in [42]. At this stage for radiological risk use can be made of the corrections suggested by ICRP [28] or UNSCEAR [42].

A.3 Risk indices for exposure to ionizing radiation

In this report the term "radiation risk" implies a probability of occurrence of carcinogenic and genetic effects due to the radiation exposure to an individual. These are related to the so-called stochastic effects of ionizing radiations. No consideration is given here to non-stochastic effects at high doses. To estimate and analyze the radiation risk, use is made of the same indices as in the general risk analysis: the individual risk R and the detriment G.

The risk index R is used in several modifications:

- an excess lifetime risk (R_{el}),
- a lifetime risk (R_{dl}) due to an exposure to radiation,
- a risk intensity, *i.e.* a change in risk per unit time, as a rule per year; the last quantity exists in two versions: r_{el} and r_{dl} corresponding to the quantities R_{el} and R_{dl}, respectively.

A.3.1 Single short-term exposure

The quantity R_{el} expresses an increase in the lifetime risk from radiation-induced cancer of the type under consideration:

$$R_{el}(e, D) = \int_e^\infty [\gamma(e,\, a,\, D) \cdot H(e,\, a,\, D) - \gamma_0(a) \cdot H(e,\, a)]\; \mathrm{d}a, \qquad \text{(A.21)}$$

where:

- $\gamma_0(a)$ is the age-specific background risk of death due to a specific spontaneous cancer,
- $H(e, a)$ is the survival function, *i.e.* the conditional probability of reaching the age a for an individual at age e (reached in the absence of the given radiation exposure),
- $\gamma(e, a, D)$, $H(e, a, D)$ are respectively the same, but with receiving a single radiation dose D at the age e.

Here and in the following, D is the equivalent dose to an organ (tissue) of the human body corresponding to the respective kind of cancer. Elsewhere the parameter defining the organ of a human body or the respective specific cancer is for simplicity omitted.

The principles underlying R_{el} are rather simple. Two identical groups, one of which is exposed to the dose D, are formed in a hypothetical experiment. Then the estimate of R_{el} for the i-th type of cancer represents the difference between the numbers of individuals who have died from the given type of cancer in the exposed and the unexposed groups.

The feature of the above estimate consists in that the individuals in the exposed group who have died from the type of cancer considered could die from the same type of cancer without any exposure to radiation, but much later. Such individuals do not contribute to the estimate of R_{el}, although the length of their life is considerably reduced.

The quantity R_{dl} represents the lifetime risk for an individual of dying from cancer induced by radiation. In the case of a single exposure to the dose D at age e, the estimate of R_{dl} is expressed as follows:

$$R_{dl}(e,\, D) = \int_e^\infty (\gamma(e,a,D) - \gamma_0(a)) \cdot H(e,\, a,\, D)\,\mathrm{d}a. \tag{A.22}$$

The difference between the estimates of R_{dl} and R_{el} is that for R_{dl} the mortality rate from the ith type of cancer in the unexposed group is multiplied by the survival function for the exposed group. This corresponds to the standard procedure of assessing the cohorts when comparing the number of deaths with the expected number in the absence of the risk sources considered.

It should be noted that for any exposure scenario the result of estimation of R_{dl} is higher than that of R_{el} by a factor roughly equal to unity plus the lifetime risk of death from the given type of cancer.

This factor is, strictly speaking, dose-independent and does not approach zero in the zero-dose limit. Thus, for all types of cancer the difference will be about 20%, and the estimates of R_{el} and R_{dl} can be considered as interchangeable.

The risk intensities r_{el} and r_{dl} are calculated by the formulas:

$$r_{el}(e,a,D) = \gamma(e,a,D) \cdot H(e,a,D) - \gamma_0(a) \cdot H(e,a), \tag{A.23}$$

$$r_{dl}(e,a,D) = \Delta\gamma(e,\, a,\, D) \cdot H(e,a,D). \tag{A.24}$$

where:

$$\Delta\gamma(e,\, a,\, D) = \gamma(e,\, a,\, D) - \gamma_0(a), \tag{A.25}$$

The other risk index, the detriment $G(e,D)$, represents the difference between the life expectancy for individuals exposed at the age e and that for unexposed individuals. It is suggested that in both cases will the individuals reach the age e. Mathematically this is expressed as follows:

$$G(e,D) = \int_e^\infty (H(e,a) - H(e,a,D))\,\mathrm{d}a. \tag{A.26}$$

Sometimes the following expression equal to Eq. (A.23) is used for $G(e,D)$:

$$G(e,D) = \int_e^\infty H(e,a,D) \cdot \Delta\gamma(e,\, a,\, D) \cdot T(a)\,\mathrm{d}a, \tag{A.27}$$

where $T(a)$ is life expectancy for a person with age a.

The determination of the values of the quantities $\gamma(e,\, a,\, D)$ is the central problem in the science of radiation carcinogenesis.

The values of these quantities will be named in what follows the primary data on radiation carcinogenesis.

The model formulas for the calculation of $\gamma(e,\, a,\, D)$ are given below.

A.3.2 Chronic and mixed exposures to radiation

Let a chronic exposure with a dose rate $\dot{D}(t)$ varying, in general, with time t start for a person at the age e. The chronic exposure is assumed to be a sum of single exposures:

$$\int \dot{D}(t) \ldots \mathrm{d}t.$$

As noted above, the total risk expressed by R or G cannot be obtained by simple summation because of the competition among risks. Only functions $m(\ldots)$ and $\gamma(\ldots)$ possesses the additive property. On this basis, the derivation of the formulas for R and G should be started from the derivation of the integral function $\Delta\gamma$ which is denoted as $\Delta\gamma(e,\, a,\, \{\dot{D}\})$:

$$\Delta\gamma(e,\, a,\, \{\dot{D}\}) = \int_e^a \Delta\gamma(t,\, a,\, d)\cdot \dot{D}(t)\,\mathrm{d}t, \tag{A.28}$$

$\Delta\gamma(t,\, a,\, d)$ is the age-specific mortality rate as a result of radiation carcinogenesis from a single exposure to unit dose d at the age t. (More correctly it is the derivative of the function $\Delta\gamma(t,\, a,\, D)$ on D at its zero value. Due to linearity of the dose functions at small values of D these expressions are equal).

The overall function $\gamma(e,\, a,\, \{\dot{D}\})$ with allowance for the chronic exposure is equal to:

$$\gamma(e,\, a,\, \{\dot{D}\}) = \gamma_0(a) + \Delta\gamma(e,\, a,\, \{\dot{D}\}), \tag{A.29}$$

$\gamma_0(a)$ is the background value. Here and elsewhere the expression $\{\dot{D}\}$ means the functional dependence of the quantity on dose rate $\dot{D}(t)$ as in Eq. (A.25).

The risk rate for a chronic exposure is expressed through Eq. (A.25) by analogy to Eq. (A.21):

$$r_{dl}(e,\, a,\, \{\dot{D}\}) = \Delta\gamma(e,\, a,\, \{\dot{D}\})\cdot H(e, a, \{\dot{D}\}). \tag{A.30}$$

It is now simple to write the formulas for the risk indices R and G:

$$R_{dl}(e,\, \{\dot{D}\}) = \int_e^\infty \Delta\gamma(e,\, a,\, \{\dot{D}\})\cdot H(e,\, a,\, \{\dot{D}\})\,\mathrm{d}a, \tag{A.31}$$

$$G(e,\, \{\dot{D}\}) = \int_e^\infty \Big(H(e,\, a) - H(e,\, a,\, \{\dot{D}\})\Big)\,\mathrm{d}a. \tag{A.32}$$

Inserting the expression (Eq. (A.25)) for $\Delta\gamma(e,\, a,\, \{\dot{D}\})$ into Eq. (A.31) and changing the order of the integration, another useful formula for $R_{dl}(e, \{\dot{D}\})$ is obtained:

$$R_{dl}(e,\, \{\dot{D}\}) = \int_e^\infty \dot{D}(t)\left(\int_t^\infty H(e,\, \tau,\, \{\dot{D}\})\cdot \Delta\gamma(t,\, \tau,\, d)\,\mathrm{d}\tau\right)\mathrm{d}t, \tag{A.33}$$

The quantity $H(e,\, a,\, \{\dot{D}\})$ is calculated by Eqs. (A.1) and (A.2) using the function $\gamma(e,\, a,\, \{\dot{D}\})$ (Eq. (A.26)) instead of $m(t)$. It should be pointed out that:

- the risk indices are calculated here in the definition of (dl);
- $H(e,\, \tau,\, \{\dot{D}\})$ is the survival function with a chronic exposure taken into account.

For a relatively low radiation risk the functions in Eqs. (A.28) and (A.29) can be replaced by the "background" function $H(e,\, \tau)$. It changes only slightly the result of the calculation. As a rule, in most of the radiological risk analyses under consideration, including that for the Chernobyl, Ural and Altai situations, such an approximation is applicable. There are no methodical or numerical difficulties for the calculation in any variant (both with an without the given approximation).

If a person is subjected to a mixed radiation exposure (a single exposure at the age e with dose D_0 plus a chronic exposure), the overall function $\gamma(e,\, a,\, D_0,\, \{\dot{D}\})$ is determined by the expression as:

$$\gamma(e,\, a,\, D_0,\, \{\dot{D}\}) = \gamma_0(a) + \Delta\gamma(e,\, a,\, D_0) + \Delta\gamma(e,\, a,\, \{\dot{D}\}). \tag{A.34}$$

The terms related to the single exposure must be introduced into Eqs. (A.31), (A.29) and (A.30).

From Eq. (A.33) it appears that a lifetime risk $R_{dl}(e,\, \{\dot{D}\})$ from a chronic exposure is not proportional to the so called life time dose. Integration of doses different in time should be done with the correction factor (the expression in the brackets in Eq. (A.33). This factor depends essentially on time (age) at exposure.

A.3.3 Specific areas of application

In the event of an accident to an NPP or other nuclear fuel cycle facility a population, depending on the concrete situation, could be subjected only to an acute (short-term) exposure, if the population is evacuated. In other cases, as a rule, a mixed (acute plus chronic) exposure of the population will occur. Such a character of exposure took place in the Kysthym and Chernobyl accidents.

For nuclear weapon tests the doses originated mainly from a single, relatively short-term exposure or from a sum of such exposures when the impact of two or more tests were significant. This is the situation, for example, for the population in the Altai territory affected by nuclear weapons tests at the Semipalatinsk test site, *eg*, [1].

The formulas given above for risk assessment are applicable to all possible cases of radiation exposure.

One should note here that use must be made of a correction factor DDREF for radiation risk from LET exposure which takes into account a higher value of this risk for an "acute" exposure (the exposure with a high dose and dose rate) as compared with a chronic exposure. ICRP [28] recommends to use DDREF=2 for solid radiogenic cancers and DDREF=1 for leukaemia.

Depending on the formulation of a task there can be many variants of the calculations concerning the radiological impact of nuclear accidents or nuclear weapon tests on the population, ranging from epidemiological research to a simple question about the total expected number of deaths in the cohort under consideration.

Below, additional variants of calculation formulas are given which would be needed in an assessment of the consequences of radioactive environmental contamination on population health from nuclear weapon tests or accidents (Chernobyl, Ural, Altai and other cases), as well as for risk management in any post-accidental situations.

Making risk assessment for the case of the impact of two tests (exposure by doses D_1 and D_2 with the time interval Δt between them), the following expression for the basic function $\Delta\gamma(\ldots)$ should be used:

$$\Delta\gamma(e,\, a,\, \Delta t,\, D_1,\, D_2) = \Delta\gamma(e,\, a,\, D_1) + \Delta\gamma(e + \Delta t,\, a,\, D_2). \qquad \text{(A.35)}$$

With this function the quantity $H(e,\, a,\, \Delta t,\, D_1,\, D_2)$, and then risk indices R and G can be calculated.

Other variants of the calculation of the radiation risk at the population level for some scenarios corresponding to the Chernobyl, Altai, Ural and other situations can be considered. Let N be the number of people in a given population group and $n(e)$ the age distribution, where e is the age at the time of an accident or a nuclear weapons test:

$$N = \int_0^\infty n(e)\,\mathrm{d}e. \qquad \text{(A.36)}$$

The total number of deaths, M, from malignant tumors due to the exposure within the given group is then given as:

$$M = \int_0^\infty n(e)R(e, \ldots)\,\mathrm{d}e, \qquad \text{(A.37)}$$

where $R(e,\, \ldots)$ is the lifetime risk of death from radiogenic cancers for a person with the age e at the moment of a single exposure or at the start of a chronic exposure. If the lifetime risk in Eq. (A.34) is replaced by the risk rate $r(e,\, \ldots)$, the rate of death occurrence in the population group (the number of deaths per unit time (per year)) is obtained:

$$\dot{M}(t,\, \ldots) = \int_0^\infty n(e) r(e,\, e+t,\, \ldots)\, \mathrm{d}e, \tag{A.38}$$

Multiplying Eq. (A.35) by $100,000/N$ gives the standard, *i.e.* referring the number of cases to 100,000 persons. If it is necessary to make calculations for some age interval, Eq. (A.15) can be used.

Below, Eq. (A.35) is applied to some concrete scenarios of the radiation exposure.

Scenario 1 *A single exposure to a dose D at the time $t = 0$.*

This scenario corresponds to the Altai situation. In this case Eq. (A.24) should be used for the risk rate $r(\ldots)$. Introducing Eq. (A.24) into Eq. (A.35) gives the following result:

$$\dot{M}(t,\, D) = \int_0^\infty n(e) \Delta\gamma(e,\, e+t,\, D) \cdot H(e,\, e+t,\, D)\, \mathrm{d}e. \tag{A.39}$$

Scenario 2 *Two exposures to single doses D_1 and D_2 with the time interval Δt between the exposures.*

This scenario is also related to the Altai situation: there are individual settlements or areas which were essentially affected by the first weapon test (in 1949) and one of the subsequent tests on the Semipalatinsk test site.

The calculation of the individual risk indices for such a scenario was considered above. Two different cohorts of people must be distinguished when calculating the individual risk indices: the first cohort received both doses D_1 and D_2; the second cohort (people born or arrived in the given area within the time interval between the tests) received only the dose D_2. The formulas for such a calculation are given above (Eqs. (A.19), (A.25) and (A.32).

The same difference must also be taken into account in calculating the number of deaths per year $\dot{M}(t,\, \ldots)$. Accordingly, the symbols $M_{12}(t,\, \Delta t,\, D_1,\, D_2)$ for the first cohort and $M_2(t,\, \Delta t,\, D_2)$ for the second one are introduced. The total value $\dot{M}_s(t,\, \ldots)$ is equal to:

$$\dot{M}_s(t,\, \ldots) = \dot{M}_{12}(t, \Delta t,\, D_1,\, D_2) + \dot{M}_2(t, \Delta t,\, D_2). \tag{A.40}$$

The first quantity is calculated by Eq. (A.34) with the function $\Delta\gamma(\ldots)$ for the double exposure, see Eq. (A.32). The expression for the second function should be written separately:

$$\dot{M}_2(t, \Delta t,\, D_2) = \int_0^{\Delta t} n(e) \Delta\gamma(e,\, e+t-\Delta t,\, D_2) \cdot H(e,\, e+t-\Delta t,\, D_2)\, \mathrm{d}e. \tag{A.41}$$

Here the integration is made only over those among the population who were born between the two tests. The method for taking the migration into account is considered below.

For the condition of a stationary population (an amount and age distribution change little on a time interval considered) one can use the following approximation in the calculation of $\dot{M}_s(t,\, \ldots)$ for the case of two tests impact:

$$\dot{M}_s(t,\, \ldots) \approx \dot{M}(t,\, D_1) + \dot{M}(t-\Delta t,\, D_2). \tag{A.42}$$

Here $\dot{M}(t,\, D)$ corresponds to a single exposure to dose D. It is easily understandable that for the conditions considered, this expression is a good approximation for assessing $M_s(t,\, \ldots)$ for the case of two tests impact: their mutual influence on a population level can as a rule be neglected.

Scenario 3 *An acute exposure to a dose D_0 and a subsequent chronic exposure with a time-dependent dose rate $\dot{D}(t)$.*

This scenario reflects the situations in the territories affected by the Kysthym and Chernobyl accidents. In this case the value of $\dot{M}(t, \ldots)$ is calculated by the formula:

$$\begin{aligned}\dot{M}(t,\, D_0,\, \{\dot{D}\}) &= \int_0^{\infty} n(e)\{r(e,\, e+t,\, D_0) + r(e,\, e+t,\, \{\dot{D}\})\}\, \mathrm{d}e \\ &+ \int_0^{t} n_b(\tau) r(0,\, t-\tau,\, \{\dot{D}\})\, \mathrm{d}\tau \qquad \text{(A.43)}\end{aligned}$$

The risk rates $r(\ldots)$ are defined above (see Eqs. (A.24) and (A.27)); $n_b(\tau)$ is the birth rate in the given population group (number of births per year) as a function of the current time τ.

If necessary, the migration is taken into account as described below. Here as elsewhere it is assumed for simplicity that D is a whole-body dose. It is sufficiently simple to extend to the case of a nonuniform exposure.

For a stationary population one can use an approximate formula like it is done for the case of two-fold exposure (Eq. (A.39)):

$$\dot{M}(t,\, D_0,\, \{\dot{D}\}) \approx \dot{M}(t,\, D_0) + \int_0^{t} \dot{M}\,(t-\tau,\, d(\tau)) \cdot \dot{D}(\tau)\, \mathrm{d}\tau\} \qquad \text{(A.44)}$$

where $\mathrm{d}(\tau)$ in the dose unit at time τ, and $\dot{M}(\ldots)$ is defined as in Eq. (A.25). If necessary, a migration is taken into account as described below.

Consideration of a possible migration of population

In the specification of a task within a given scenario it may be necessary to allow for the migration of the population. In any scenario, departing people decrease the risk in the local population, because they carry away both possible future cancer cases and the other risks. The newly arrived people can make contribution to the risk considered if they receive the second dose (scenario 2) or appear in a zone of a chronic exposure (scenario 3). Allowance for the migration must be made with care: "the competition between risks" applies also to the migration. The role of this competition in the risk analysis was discussed above.

First of all a method of making allowance for the migration (departure) of the population which practically refers similarly to all scenarios considered above is described. Let $m_M(e,\, e+t)$ be the age-specific migration (departure) coefficient or, in other words, the density of probability that an individual who was at the age e at the moment of the exposure will depart in t years. The migration can be considered like a mortality (leaving) within the given cohort (population group).

As a consequence, in the calculation formulas for $M(t,\, \ldots)$ using the survival function $H(e,\, e+t, \ldots)$ one should multiply this function by a factor which properly takes into account the migration:

$$H_m\,(e,\, e+t) = \exp\left(-\int_e^{e+t} m_m\,(e,\, a')\, \mathrm{d}a'\right). \qquad \text{(A.45)}$$

The migration - arrival of people on a radioactive contaminated territory for living - can be taken into account as indicated above making allowance for children being born (Eq. (A.41)). The only difference is that people appear (as if they are born) at any age but not at age $e = 0$. In this case instead of quantity $n_b(\tau)$ one should use $n(e,\, \tau)$ which is an age distribution of migration (arrival) rate at time τ and add the integration through the age at the time of arrival.

A.4 Models of radiation risk (carcinogenesis)

The exact and complete theory of the radiation carcinogenesis (RC) is absent. In such circumstances, phenomenological models of RC (models describing the age specific risk $\gamma(e, a, D)$) are used in the radiation risk assessment. These models have been produced using results of epidemiological studies and radiobiological experiments.

A.4.1 Models of absolute and relative risks

All models developed and recommended by the competent international and national organizations for radiation risk assessment belongs to one of the following two types (from view-point of their relation with spontaneous cancer risk):

- a model of absolute (or additive) risk,
- a model of relative (or multiplicative) risk.

In the general form they are written as the following:

(A) Absolute (or additive)

$$\gamma(e, a, D) = \gamma_0(a) + h_{abs}(e, a) \cdot f_{abs}(D), \tag{A.46}$$

(B) Relative (or multiplicative)

$$\gamma(e, a, D) = \gamma_0(a) \cdot (1 + g_r(e, a) \cdot f_r(D)). \tag{A.47}$$

Here the age-specific background death rate due to a specific cancer, $\gamma_0(a)$, is defined above; $g_{abs}(e, a)$, $g_r(e, a)$ are factors allowed to depend on age at time of exposure, time, etc.; $f_{abs}(D)$ and $f_r(D)$ are functions of dose D. Here as elsewhere the parameter denoting a specific cancer is omitted.

The radiation risk estimations in ICRP Publication 27 [23] were made using the absolute risk models. In ICRP Publication 45 [26], estimations by the relative risk models were added.

Not addressing the further history of developing and using these models it should be noted that the relative risk models now are more preferable for the most radiogenic cancer estimates.

A.4.2 Sets of radiation risk models

At present there are few sets of radiation risk models developed by the international and national competent organizations: models from UNSCEAR 88 [42] and UNSCEAR 94 [43], BEIR V [44], UK NRPB [38] etc., all using absolute and relative risks. The differences between them come from different grouping of human body organs in choosing the concrete models and from different accounting for dependence of the radiation cancer risk on age at exposure and time.

B Clean-up of radioactively contaminated land

Per Hedemann Jensen

B.1 Introduction

Clean-up of a contaminated territory would be based on dose reduction and cost associated with the clean-up. Action levels for clean-up based on avertable individual doses are levels above which clean-up is undertaken and below which it is not. An optimized action level for clean-up would correspond to the level of avertable dose at which the marginal increase in avertable dose become just less valuable than the increased marginal cost. The action level for clean-up can thus be defined as the lowest level at which clean-up to reduce doses is justified. In other words, the action level corresponds to the maximum acceptable level of residual dose attributable to the contamination without clean-up. This Section provides a simple example of how a generic dose level for justified clean-up of contaminated areas might be determined.

B.2 Urban and semi-urban areas

The optimum intervention criteria for clean-up operations would depend on many factors. The most important factors are the avertable individual doses to the population, ΔE_{ind}, the efficiency of the decontamination (fraction of activity remaining), η, and the monetary costs of the cleaning operation, c_{clean}. The clean-up costs, c_{clean}, can be expressed as:

$$c_{clean} = c_{waste}w + c_{lab}\varepsilon + c_{equip}\delta \tag{B.1}$$

where c_{waste} is the cost per unit mass of produced waste, w is the waste produced per unit area, c_{lab} is the labor cost per unit time, ε is the working time spent per unit area, c_{equip} is the equipment cost per unit time, and δ is the time of equipment use per unit area. The parameters w, ε, and δ, would all depend on the clean-up efficiency, η.

The clean-up costs would depend on the type of area contaminated as the clean-up procedures would be different for the different areas. Clean-up of *urban areas* would include street sweeping, firehosing, asphalt planing, removal of vegetation and removal of soil. Clean-up of *agricultural areas* would include removal of soil and removal of vegetation. Clean-up of *forest areas* would include removal of trees, removal of under-vegetation and removal of soil.

The clean-up costs would involve the disposal of waste which could be the dominating cost in the clean-up of large areas. Removal of the upper one centimeter of soil in an area of 1 km^2 would create 10,000 m^3 of soil waste with a cost of disposal of the order of \$ 10^6 per km^2. For an urban area with the same characteristics as the city of Copenhagen the costs of clean-up, c_{clean}, have been estimated to the values shown in Table B1, based on the Nordic research program on waste and decommissioning (KAN-Programme).[1]

[1] *Cleanup of Large Radioactive Contaminated Areas and Disposal of Generated Waste. Final Report of the KAN2 Project, TemaNord 1994:567, February 1994*

Table B1. Costs for different clean-up methods in an area of 250 km^2 of a city with the characteristics of Copenhagen.

Clean-up method	Clean-up costs (\$·km^{-2})		
	Clean-up	Transport[a)]	Wages[c)]
Soil removal	400,000-800,000[b)]	-	100,000-200,000
Grass cutting	5,000-10,000	2,000-5,000	5,000-10,000
Firehosing	5,000-15,000	1,000-4,000	5,000-10,000
Asphalt planing	600,000-1,000,000	40,000-80,00	70,000-150,000

[a)] Transport of waste
[b)] Includes transport of waste
[c)] Based on Western countries with a salary of \$ 15 per hour

Taking into consideration only the avertable dose to the population, the doses to the workers engaged in the clean-up and the monetary costs of the cleaning operation the following factors would enter the optimization process for determining the intervention level for the clean-up:

- the number of people living in the contaminated area, N_{pop}
- the size of the contaminated area, A
- the monetary cost of the clean-up per unit area, c_{clean}
- the number of workers carrying out the clean-up, N_{work}
- the collective dose to the clean-up personnel, $S_{work} = E_{work}\,N_{work}$
- the efficiency of the clean-up operation (fraction of activity removed), η
- the reduction factor of dose rate, $f(= 1/(1-\eta))$
- the monetary cost of relocation per person and unit time, c_{rel}
- the equivalent monetary cost of the unit collective dose, α

In the optimisation of intervention levels for clean-up two different situations will be considered. Firstly, a contaminated residential area from which people have not been relocated, and, secondly, a contaminated residential area from which people have been relocated because the avertable doses by relocation exceed the intervention level.

B.2.1 Areas from which people have not been relocated

The condition for a clean-up operation to be justified is that the monetary value of the avertable collective dose, ΔS, from the clean-up is larger than the sum of the monetary value of the collective dose to the clean-up workers and the cost of the clean-up operation:

$$\alpha\,\Delta S \geq \alpha E_{work} N_{work} + c_{clean} A \approx c_{clean} A \tag{B.2}$$

The cost of the collective dose the clean-up workers will normally be marginal compared to the other clean-up costs and therefore the first term in the above equation can be disregarded.

The annual dose, E_{an}, from activity deposited in urban and semi-urban environments will, as an approximation, be proportional to the surface contamination density at each surface type. The annual dose would thus be:

$$E_{an} \propto x_{soil}v_{soil} + x_{grass}v_{grass} + x_{house}v_{house} + x_{asphalt}v_{asphalt} \tag{B.3}$$

where:

- x is the fraction of the given surface type, and

- v is the relative deposition velocity for that surface type.

When the clean-up efficiency for the different surfaces is η_i, which defines the reduction factor, f_i, as 1/(1 - η_i), the annual dose after clean-up, $E_{an,clean}$, can be described as:

$$\begin{aligned} E_{an,clean} &\propto (1-\eta_{soil})x_{soil}v_{soil} \\ &+ (1-\eta_{grass})x_{grass}v_{grass} \\ &+ (1-\eta_{house})x_{house}v_{house} \\ &+ (1-\eta_{asphalt}x_{asphalt}v_{asphalt} \end{aligned} \tag{B.4}$$

The effective dose reduction factor, f, by clean-up of the different surfaces can then be described as:

$$f = \frac{E_{an}}{E_{an,clean}} = \frac{\sum_i x_i\, v_i}{\sum_i (1-\eta_i)\, x_i\, v_i} \tag{B.5}$$

If T is the time period over which the collective dose is accumulated, the avertable collective dose, ΔS, over the time, T, is related to the (fairly constant) annual individual effective dose, E_{an}, as:

$$\begin{aligned} \Delta S &= N_{pop} \left[\int_0^T E_{an}(t)\, \mathrm{d}t - \frac{1}{f} \int_0^T E_{an}(t)\, \mathrm{d}t \right] \\ &= N_{pop} \frac{f-1}{f} E_{an}\, T \end{aligned} \tag{B.6}$$

The justified annual individual effective dose, E_{an}, before clean-up can be found from the following considerations. The avertable collective dose over time, T, with clean-up will determine the justified value of the annual individual dose before clean-up, E_{an}, as:

$$\alpha\, \Delta S = \alpha\, N_{pop} \frac{f-1}{f} E_{an}\, T \geq c_{clean} A \tag{B.7}$$

With a population density $P_{pop} = N_{pop}/A$, a dose reduction factor, f, equal to $1/\eta$, the justified value of the annual effective dose before clean-up, E_{an}, can then be found from the above equation to be:

$$(E_{an})_{just} = \left(\frac{f}{f-1} \right) \frac{c_{clean}}{\alpha\, P_{pop}\, T} \tag{B.8}$$

Fig. B1 illustrates the effect of a clean-up operation which results in a reduction of the collective dose by a factor, f.

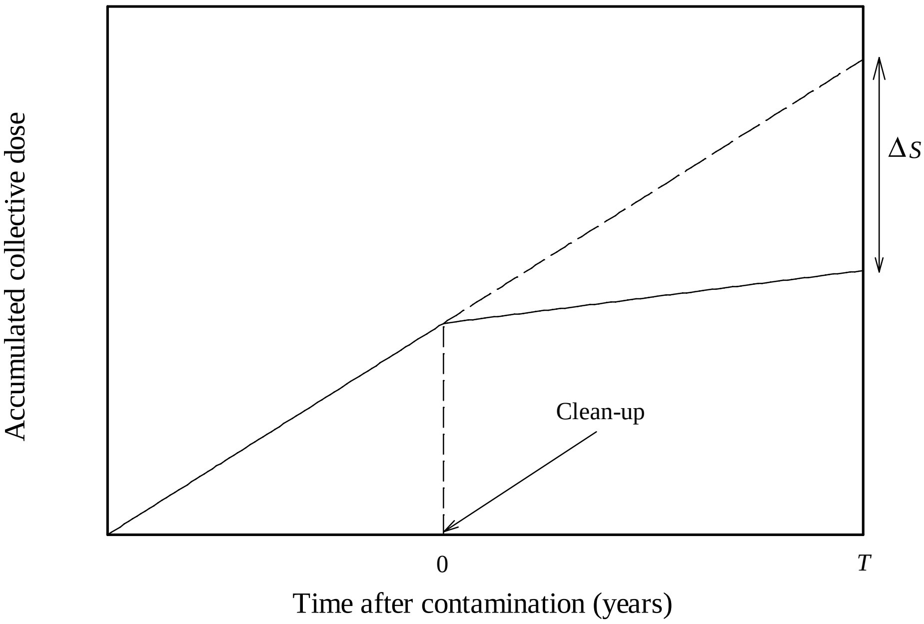

Figure B1. Avertable collective dose from clean-up with efficiency of the clean-up, η, which expresses the fraction of the radioactive material removed after clean-up.

Calculations of the justified annual effective dose, E_{an}, before clean-up of urban and semi-urban areas have been made with the program Crystal Ball. For an assumed clean-up efficiency, η, of soil removal, grass cutting, firehosing of houses and asphalt planing the total clean-up costs per unit area were calculated as:

$$\begin{aligned} c_{clean} &= x_{soil}c_{clean,soil} + x_{asphalt}c_{clean,asphalt} \\ &+ x_{house}c_{clean,house} + x_{grass}c_{clean,grass} \end{aligned} \qquad \text{(B.9)}$$

Assigning distributions to all parameters, a range of justified values of the annual individual dose before clean-up has been calculated. The values of the parameters and the parameter distributions used in the calculations are shown in Table B2.

Table B2. Parameter values and their distributions used in the optimization calculations.

Parameter		Uniform distribution	Log-normal distribution	
			Central value	Standard deviation
Soil removal cost, \$ km^{-2}		400,000-800,000	600,000	200,000
Wages, \$ km^{-2}		100,000-200,000	150,000	50,000
Grass cutting cost, \$ km^{-2}		5,000-10,000	7,500	2,200
Transport, \$ km^{-2}		2,000-5,000	3,500	1,000
Wages, \$ km^{-2}		5,000-10,000	7,500	2,500
Firehosing cost, \$ km^{-2}		5,000-15,000	10,000	3,000
Transport, \$ km^{-2}		1,000-4,000	2,500	800
Wages, \$ km^{-2}		5,000-10,000	7,500	2,500
Asphalt planing cost, \$ km^{-2}		600,000-1,000,000	800,000	300,000
Transport, \$ km^{-2}		40,000-80,000	60,000	20,000
Wages, \$ km^{-2}		70,000-150,000	110,000	35,000
Pop. dens., km^{-2} (urban)		300-600	450	200
Pop. dens., km^{-2} (semi-urban)		100-200	150	60
Rel. deposition roads, v_{road}		0.2-0.5	0.30	0.08
Rel. deposition houses, v_{house}		0.05-0.2	0.12	0.03
Rel. deposition grass, v_{grass}		0.8-1.2	1.0	0.20
Rel. deposition soil, v_{soil}		0.8-1.2	1.0	0.20
Fraction houses	Urban	0.50	0.50	-
X_{house}	Semi-urban	0.30	0.30	-
Fraction roads	Urban	0.25	0.25	-
X_{road}	Semi-urban	0.25	0.25	-
Fraction soil	Urban	0.20	0.20	-
X_{soil}	Semi-urban	0.30	0.30	-
Fraction grass	Urban	0.05	0.05	-
X_{grass}	Semi-urban	0.15	0.15	-
Soil removal efficiency, η_{soil}		0.5-0.8	0.70	0.14
Grass cutting efficiency, η_{grass}		0.2-0.6	0.40	0.06
Firehosing efficiency, η_{house}		0.1-0.5	0.30	0.03
Asph. plan. efficiency, $\eta_{asphalt}$		0.6-0.9	0.80	0.12
Cost of unit dose, α, \$ Sv^{-1}		10,000-40,000	25,000	8,000
Integration time, T, years		30-300	200	50
Relocation costs, \$ month^{-1}		200-500	200	70

The results of the Crystal Ball calculations with the above values and distributions are shown in Table B3. The reason why the results for semi-urban areas are approximately four times higher than for urban areas is mainly due to the difference in population density. For more dense populated areas the avertable dose by the clean-up operation per unit reduction in dose rate will result in a correspondingly higher avertable collective dose over the period considered.

Table B3. Annual dose levels, E_{an}, in mSv/year above which clean-up is justified based on avertable dose and monetary costs of the clean-up of urban and semi-urban areas.

Area type	Distribution	Percentiles			Mean	Median
		2.5%	50%	97.5%		
Urban	uniform	0.14	0.43	2.30	0.60	0.40
	log-normal	0.10	0.34	1.20	0.40	0.30
Semi-urban	uniform	0.49	1.50	7.80	2.20	1.50
	log-normal	0.36	1.20	3.90	1.40	1.20

The justified annual dose level, E_{an}, before clean-up can be considered as the $actionlevel, AL$ for introducing clean-up. If the actual dose level, E_{act}, (from all relevant exposure pathways) is greater than the AL, clean-up would normally be justified.

The residual dose *after* an optimized clean-up operation can be either lower or greater than the AL. This will depend on the ratio E_{act}/AL. If the ratio is significantly higher than the effective dose reduction factor, f, the residual dose after an optimized clean-up would still be higher than the AL. If the ratio is of the same order of magnitude or lower than, f, the residual dose would most likely be lower than the AL.

If the actual dose level is much higher than a few millisieverts per year this would invoke the temporary countermeasures appropriate for the later phases of a nuclear or radiological emergency. Where assessed individual doses are in the region of 10 mSv/y or greater, remediation will almost always be justified. Doses of that magnitude, corresponding to a lifetime dose of about 1 Sv, would, in any case, invoke permanent relocation if the exposure rate is chronic or semi-chronic. However, the generic justification calculations performed in this Appendix - although of a rather simple nature - seem to indicate that an AL for clean-up in terms of annual dose before clean-up would fall in the range from a fraction of a millisievert to a few millisievert per year.

Operational quantities are the parameters actually measured to evaluate or to demonstrate compliance with a particular cleanup criterion. The action level, AL, would generally be expressed in dose, eg annual dose. However, for many practices and for some interventions, these criteria can generally be converted into more readily measurable operational quantities. Such quantities are derived by mathematical models where all significant exposure pathways and the projected relevant behaviour of the exposed population group. Some models may only be suitable and useful for screening, while other models may be suitable for site specific application.

B.2.2 Areas from which people have been relocated

The condition for a clean-up operation to be justified in areas from which people have been relocated is that the saved relocation costs by the accelerated return time, $\Delta\tau$, is larger than the sum of the monetary value of the collective dose to the clean-up workers and the cost of the clean-up operation itself:

$$c_{rel} N_{pop} \Delta\tau \geq \alpha E_{work} N_{work} + c_{clean} A \tag{B.10}$$

where c_{rel} is the relocation cost per person and unit time. The dose rate at the return time is here assumed to be equal in the situations with and without clean-up. The accelerated return time can be found from the above equation as:

$$\Delta\tau \cong \frac{c_{clean}}{c_{rel}} \frac{A}{N_{pop}} = \frac{c_{clean}}{c_{rel}} \frac{1}{P_{pop}} \tag{B.11}$$

as the equivalent cost of the doses the workers is only marginal compared to the clean-up costs, c_{clean}. The value of $\Delta\tau$ can be expressed by the half-life of the deposited radionuclides as:

$$\Delta\tau = \frac{T_{1/2}}{\ln(2)} \ln(f) \tag{B.12}$$

The justified value of $\Delta\tau$ can then be expressed by the half-life of the deposited radionuclides as:

$$T_{1/2} = \frac{\ln(2)}{\ln(f)} \frac{c_{clean}}{P_{pop}\, c_{rel}} \tag{B.13}$$

The half-life, $T_{1/2}$, corresponding to the justified accelerated return time has been calculated from Crystal Ball, and the results are shown in Table B4. It is not justified to clean areas for half-lives less than the values shown as the costs from the clean-up will be greater than the saved relocation costs. It is therefore better to wait for the decay of activity before the area is reinhabited.

Table B4. Half-life of contaminant, $T_{1/2}$, in months above which clean-up is justified based on the break-even between clean-up costs and saved relocation costs.

Area type	**Distribution**	**Percentiles**			**Mean**	**Median**
		2.5%	**50%**	**97.5%**		
Urban	uniform	1.1	2.1	4.3	2.3	2.1
	log-normal	1.1	3.8	12.0	4.5	3.8
Semi-urban	uniform	3.8	7.4	15.5	8.0	7.4
	log-normal	3.9	13.0	41.0	15.4	13.0

Bibliographic Data Sheet **Risø-R-831(EN)**

Title and author(s)

EU-CIS Joint Study Project 2
Intervention Criteria in CIS, Risk Assessments and Non-Radiological Factors in Decision-Making

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ISBN	ISSN
87-550-2085-2	0106-2840

Dept. or group

Section of Applied Health Physics, Department of Safety

Date

May 1996

Journal No.	Project/contract No.
	AHF 02932-00

Pages	Tables	Illustrations	References
70	19	10	45

Abstract (Max. 2000 char.)

An extensive radiation risk estimation methodology has recently been developed in Russia and used for estimates of risk in exposed populations in the republics of Russia, Belarus and Ukraine. Results based on demographic data for the three republics are presented and compared with risk estimates from the EU risk model ASQRAD.

The intervention criteria in the CIS republics have been evolving since the Chernobyl accident. The development of criteria in each of the three republics has been analyzed and the CIS-criteria have been compared to international guidance on intervention.

After a nuclear or radiological emergency both radiological and non-radiological protection factors will influence the level of protective actions being introduced. The role of non-radiological protection factors in the overall optimization of health protection is addressed. It is argued that optimization of the overall health protection is not a question of developing radiation protection philosophy to fully include socio-psychological factors. It is rather a question of including these factors - in parallel with the radiological protection factors - in cooperation between radiation protection experts and psychological specialists under the responsibility of the decision maker.

Descriptors INIS/EDB

A CODES; BELARUS; CESIUM 137; CHERNOBYLSK-4 REACTOR; EMERGENCY PLANS; FOOD; MATHEMATICAL MODELS; MILK; POPULATION RELOCATION; RADIATION ACCIDENTS; RADIATION DOSE DISTRIBUTIONS; RADIATION DOSES; RADIATION HAZARDS; RADIATION PROTECTION; REMEDIAL ACTION; RISK ASSESSMENT; RUSSIAN FEDERATION; SURFACE CONTAMINATION; UKRAINE