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ANALYSIS OF COUNTERMEASURES APPLIED FOLLOWING THE CHERNOBYL ACCIDENT AND LESSONS LEARNED

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Timing of the phases

Place	Phase	Timing
Off-site	Early phase	26 April–5 May 1986 (end of massive radioactive releases)
	Intermediate phase	5 May 1986– May 1991 [adoption of laws on the legal status of contaminated areas in Belarus (February), Ukraine (February), and the Russian Federation (May)]
	Long-term phase	First semester of 1991 onwards
On-site	Early phase	26 April–5 May 1986 (end of massive radioactive releases)
	Intermediate phase	5 May 1986–November 1986 (achievement of construction of the sarcophagus)
	Long-term phase	November 1986 onwards

Strategy before Chernobyl (1/3)

Two main documents:

- Standards of Radiation Safety (SRS-76);
(established the dose limits to the workers and the public)

- "Criteria for decision making on measures …."
(established the radiological criteria to introduce countermeasures in the early phase)

Strategy before Chernobyl (2/3)

Parameter	Exposure level	
	A	B
Whole-body dose from external exposure, Gy	0.25	0.75
Absorbed dose to thyroid from intake of radioiodines, Gy	0.25-0.30	2.5
Time-integrated concentration of ^{131}I in ground-level air, kBq s L^{-1}		
children	1,480	14,800
adults	2,590	25,900
Total integrated intake of ^{131}I with foodstuffs, kBq	55.5	555
Max concentration of ^{131}I in fresh milk, kBq L^{-1} or in daily diet, kBq d^{-1}	3.7	37
Ground deposition density of ^{131}I on pasture, kBq m^{-2}	25.9	259

Strategy before Chernobyl (3/3)

Countermeasures in the early phase:

- sheltering;
- evacuation;
- intake of stable iodine to block the thyroid;
- restrictions of the consumption of foodstuffs.

Dosage of KI pills were recommended at that time:

- adults and children over 2 years old – 250 mg of KI;
- children up to 2 years old – 40 mg of KI.

Urgent protective actions (1/4)

Sheltering

Was not applied anywhere except for a part of the residents of Pripyat town, located 4 km from the damaged reactor.

Urgent protective actions (2/4)

Evacuation in 1986

Populations

About 116,000 people (24,700 Belarusians, 91,400 Ukrainians, and 186 Russians).

Dates

Pripyat town – April 27, 1986
Villages from the 10-km zone – May 2-3
Villages from the 30-km zone – May 3-7
Villages outside the 30-km zone – May-September

Urgent protective actions (3/4)

Administration of stable iodine

Pripyat town - on April 26-27, 1986.

Belarusian part of the 30-km zone – on May 1-4

Ukrainian part of the 30-km zone – on May 2-7

Outside the 30-km zone – from middle of May through August

Remark: Intake of stable iodine for the residents of Pripyat was effective. For the other populations it was too late and ineffective.

Urgent protective actions (4/4)

Restrictions of the consumption of foodstuffs

No restrictions were made on the consumption of contaminated foodstuffs during the early phase of the accident.

The residents of contaminated areas consumed cows' milk contaminated with ^{131}I, and this resulted in high doses to the thyroid, especially among small children.

Dose to the thyroid (1/4)

Monitoring of the ^{131}I thyroidal content for the public

Territories, populations and dates in 1986:

- Belarus 200,000 residents. May 5 through June
- Ukraine 150,000 residents. May 5 through June
- Russia 45,000 residents. May 15 through June

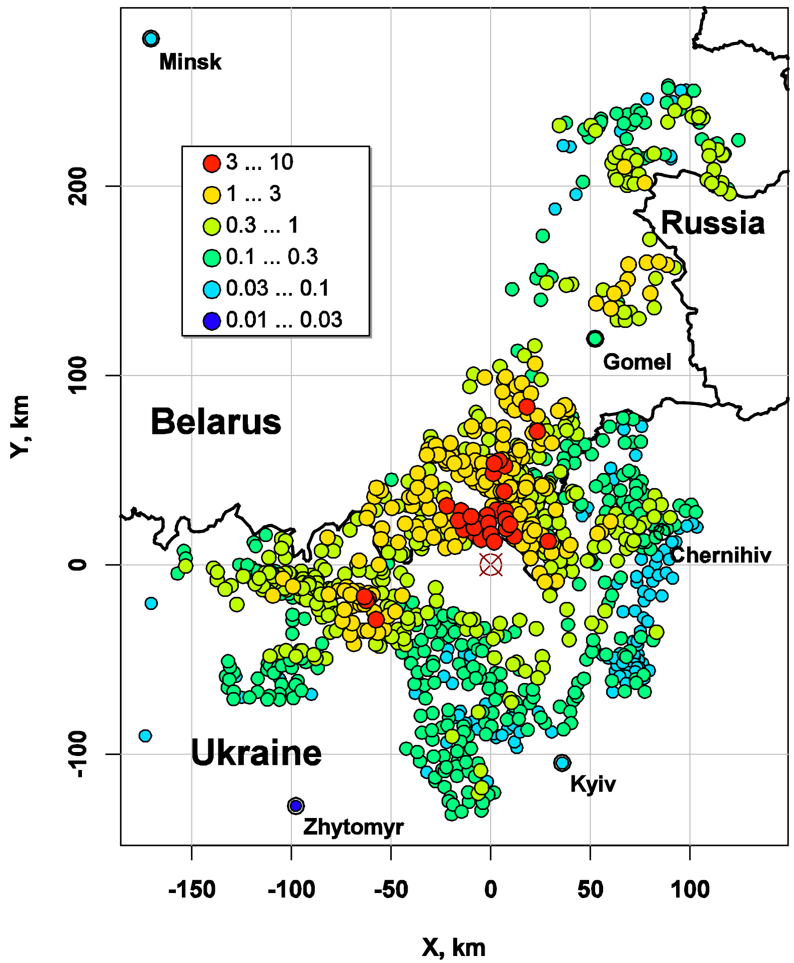
Dose to the thyroid (2/4)

Individual doses to ^{131}I derived from direct thyroid measurements for the Belarusian residents (Savkin and Shinkarev, 2007)

Area	Age-group	Thyroid dose, Gy		
		<0.3	0.3-2.5	>2.5
Evacuated villages from three southern raions of Gomel Oblast	0-3y	5.6%	39.8%	54.6%
	Adults	32.5%	60.0%	7.5%
Non-evacuated villages of three southern raions of Gomel Oblast	0-3y	14.5%	55.8%	29.8%
	Adults	65.3%	33.7%	0.9%
Contaminated territories of Mogilev Oblast	0-3y	61.1%	37.1%	1.9%
	Adults	94.0%	6.0%	0.02%

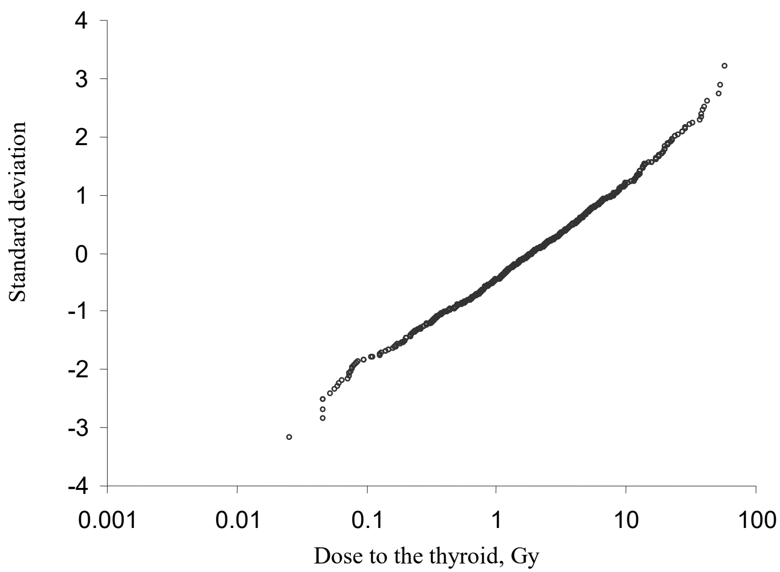
Dose to the thyroid (3/4)

Average thyroid doses (Gy) to ^{131}I for the children (0-17)y in the Belarusian and Ukrainian settlements based on direct thyroid measurements (Jacob et al, 2006)

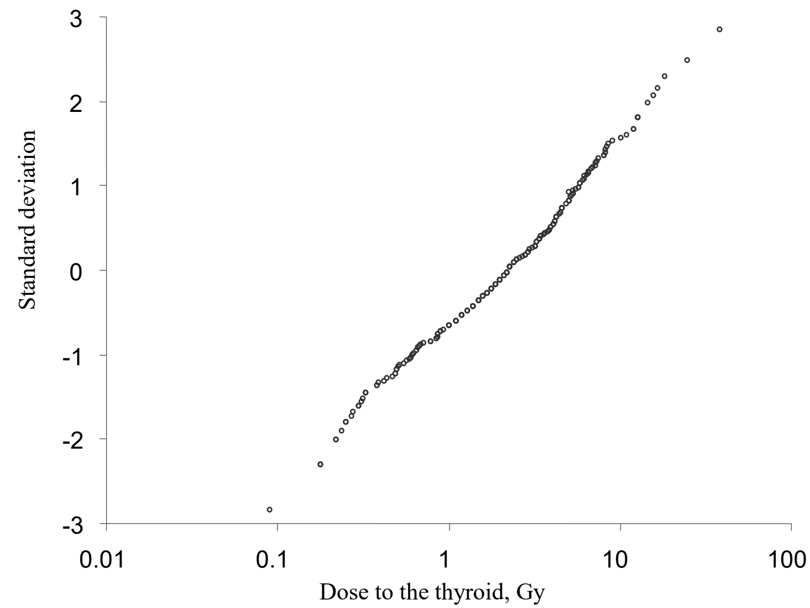


Dose to the thyroid (4/4)

Evacuated children (0-6) y from three southern raions of Gomel Oblast, median =2.0 Gy, GSD=4.4 (688 pers.)



Evacuated children (0-17) y from village Pogonnoe of Khoiniki raion of Gomel Oblast, median =2.1 Gy, GSD=3.1 (226 pers.)



Strategy for the intermediate phase (public)

<u>on 12 May 1986:</u> A whole-body equivalent dose of 100 mSv (external – 50 mSv; internal – 50 mSv) for the first year (26 April 1986 to 25 April 1987).

<u>on 23 April 1987:</u> An annual dose of 30 mSv (internal – 10 mSv) for the second year (26 April 1987 to 25 April 1988).

<u>on 18 July 1988:</u> Annual doses of 25 mSv (internal – 8 mSv) for the third and fourth years following the accident. Therefore, a dose to members of the general public of up to 173 mSv was allowed from the time of the Chernobyl accident until 1 January 1990.

Protective actions at the intermediate phase (1/4)

Relocation

The criteria were approved by the Main State Sanitary Physician of the USSR on 12 May 1986 (below – the exposure rate decay corrected to 10 May 1986)

- > 20 mR h^{-1} – the exclusion zone, the area from which the residents were removed permanently.
- 5 – 20 mR h^{-1} – the temporal evacuation zone, the area to which the relocated residents were supposed to return after normalisation of radiological conditions.
- 3 – 5 mR h^{-1} – the strict control zone, the area from which children and pregnant women were removed for the summer of 1986.

Protective actions at the intermediate phase (2/4)

Re-evacuation

In August 1986 the Government Commission of the USSR ordered to investigate possible re-evacuation of the 47 contaminated settlements in the evacuation zone. Re-evacuation was recommended for the residents of 27 rural settlements (12 in Belarus and 15 in Ukraine) after the construction of shelters.

The re-evacuation criteria:

$q(^{137}Cs) < 555$ kBq m^{-2}; $q(^{90}Sr) < 111$ kBq m^{-2}; $q(^{239,240}Pu) < 3.7$ kBq m^{-2}; exposure rate (decay corrected Sept.1986) < 0.2 mR h^{-1}.

Meeting criteria means that the residents will not exceed the dose for 1987 (30 mSv) with a factor of 1.5-2.

12 Belarusian settlements had been re-evacuated by the winter of 1986–1987. However, the Ukrainian authorities decided that re-evacuation would be economically and socially undesirable, and did not support re-evacuation.

Protective actions at the intermediate phase (3/4)

Restrictions of the consumption of foodstuffs

On 6 May 1986, the Main State Sanitary Physician of the USSR adopted the temporal permissible levels (TPLs) of ^{131}I in foodstuffs:

- 3.7 kBq L^{-1} for milk and water,
- 18.5–74 kBq kg^{-1} for dairy products and leafy vegetables.

On 30 May 1986, the TPLs were revised and significantly decreased to total beta activity:

- 0.37 kBq L^{-1} for milk and water,
- 0.37–18.5 kBq kg^{-1} for other foodstuffs.

Protective actions at the intermediate phase (4/4)

Decontamination

Decontamination work commenced at the end of May 1986. The permissible levels of contamination were based on the dose limits for the whole body and skin.

Decision making on decontamination was based on two criteria:

(i) the contamination zone in which the item was located (almost all of the decontamination work was conducted in the obligatory resettlement zone);

(ii) the social and economic significance of the decontaminated item.

From 1986 to 1987, a major improvement in the situation was achieved through a radical reduction of exposure rates in various frequently visited sites in different settlements. This resulted in reducing the external dose for various professionals and some age groups (e.g. children) by an average of 30%.

By 1989, full decontamination of settlements had been virtually completed. Assessment of its efficiency showed that, on average, it did not exceed 10%.

Doses to the public in the intermediate phase

Since 1987, the doses to the public in contaminated areas were mainly due to:

- external exposure from ^{134}Cs and ^{137}Cs deposited on the ground;
- internal exposure due to contamination of foodstuffs by ^{134}Cs and ^{137}Cs.

The average effective dose from ^{134}Cs and ^{137}Cs received during the first 10 years by the residents of contaminated areas is about 10 mSv. The median effective dose is about 4 mSv.

Approximately 10,000 members of the public received effective doses >100 mSv.

The lifetime effective dose is expected to be about 40% higher than the dose received during the first 10 years following the accident.

Strategy for emergency responders

National regulations established before the accident <u>for civilian workers</u>:

- in 1986, the maximum dose limit was 250 mSv.
- in 1987, the annual dose limit was (50-100) mSv depending on the type of work performed on-site. Dose of up to 250 mSv was allowed for extremely important interventions.
- in 1988, the annual dose limit was 50 mSv for all workers, except those involved in decontamination of the engine hall inside the sarcophagus (dose limit of 100 mSv).
- from 1989 onwards, the annual dose limit was 50 mSv for all workers, without exception. These civilian workers were managed as if they were workers in a planned exposure situation.

<u>For military workers</u>, a dose limit of 500 mSv, corresponding to exposures during war time, was applied until 21 May 1986. After that the dose limit was 250 mSv. From 1987 onwards, the dose limits were the same for military and civilian personnel.

Doses to emergency responders

The highest doses were received on-site on April 26, 1986. Acute radiation sickness was confirmed for 134 emergency responders:

- < 2.1 Gy – 41 responders;
- (2.2 – 4.1) Gy – 50 responders;
- (4.2 – 6.4) Gy – 22 responders;
- (6.5 – 16) Gy – 21 responders.

An official registry of recovery responders was established in 1986. The average recorded external doses were as follows:

- 1986 – 170 mSv;
- 1987 – 130 mSv;
- 1988 – 30 mSv;
- 1989 – 15 mSv.

Strategy for the long-term phase (public)

On 22 November 1988, the USSR Scientific Committee for Radiation Protection recommended a limit of 350 mSv for the lifetime effective dose from the Chernobyl fallout for members of the public. In 1990–1991, a team from IAEA, accordingly to the request of the USSR Government, provided an international expertise and made a conclusion that from the point of view of radiation protection the 350-mSv lifetime dose limit was too severe. However, the 350-mSv limit was rejected by the state officials due to pressure from the public and mass media.

By the end of 1991, the USSR had split into 15 separate countries. Of these, Belarus, Ukraine, and the Russian Federation had been strongly affected by the accident. Each of these three countries implemented their own national policy for radiation protection of the public, but all were influenced by the 1990 ICRP recommendation to adopt an annual effective dose limit for the public of 1 mSv in regulated situations.

Protective actions at the long-term phase (1/4)

Radiation monitoring

was widely applied in contaminated areas to assess individual doses for members of the public:

a) External doses

(i) thermoluminescent dosimeter measurements;

(ii) measurements of exposure rates and radionuclide concentrations in soil and population surveys on indoor and outdoor occupancy as a function of age, season, occupation, and type of dwelling.

b) Internal doses

(i) whole-body counting;

(ii) estimation of dietary intake from measured concentrations in foods and standard consumption assumption.

Protective actions at the long-term phase (2/4)

Long-term or permanent relocation

Wide-scale relocation was conducted in Belarus and Ukraine in the 1990s.

In Belarus, the populations of all villages in the primary relocation zone (i.e. where ^{137}Cs deposition density exceeded 1480 kBq m^{-2}) were relocated from 1991 to 2000.

Over the same time period, almost 300,000 people were relocated or self-moved from areas where ^{137}Cs deposition density exceeded 37 kBq m^{-2}.

Protective actions at the long-term phase (3/4)

Agricultural protective actions

In 1991–1997, a full-scale set of countermeasures was applied in regions where agricultural production did not meet the radiological standards.

From 1998 onwards, there has been a progressive return to normal conditions, defined as annual dose <1 mSv. The rehabilitation of agricultural lands with ^{137}Cs contamination >1480 kBq m^{-2} has also been considered.

The countermeasures applied in the intermediate and late phases of the Chernobyl accident to agricultural production in contaminated areas in Belarus, the Russian Federation, and Ukraine allowed for aversion of the internal collective dose of approximately 12,000–19,000 man-Sv for the period 1986–2006, or 30–40% of the internal collective dose that would have been received without the use of countermeasures (excluding thyroid dose).

Protective actions at the long-term phase (4/4)

Health surveillance

Follow-up of people with clinically significant deterministic effects

134 people were diagnosed with acute radiation syndrome (ARS). 28 died within a few months (95% died had received whole-body doses >6.5 Gy). Currently patients with ARS are under clinical surveillance in Moscow and Kiev.

Health monitoring programs

Those programs encompass recovery responders and residents of the most contaminated areas, including their offspring. Up to the end of 1991, the All-Union Distributed Clinico-Dosimetric Registry had information on 659,292 people. After the dissolution of the USSR, national Chernobyl registries continued to be operated independently in Belarus, the Russian Federation, and Ukraine. A number of specialised population-based registries were set up, including those for thyroid cancer and haematological malignancies.

Lessons (1/6)

The strategy on the introduction, implementation, and withdrawal of countermeasures is driven by relevant national radiological criteria.

Lessons (2/6)

Early notification of the people and immediate introduction of emergency plans are extremely important.

Lessons (3/6)

Large-scale monitoring of thyroidal iodine content among the public is a solid basis for reliable estimates of individual thyroid doses. Early start of those measurements allows their use for adjusting the time and scale of countermeasures.

Lessons (4/6)

Timely implementation of urgent countermeasures in the early phase of a radiological emergency is the most effective means to decrease radiation doses to the population.

Effectiveness of the countermeasures (in terms of cost per unit of averted dose) following the Chernobyl accident

Countermeasure	USD per 1 man-Sv	Area, date
External exposure		
Sheltering	0.02-1	Pripyat, April 26-27, 1986
Relocation	130,000-500,000	Contaminated areas, 1990
Internal exposure		
Iodine prophylaxis	0.02-0.1	April-May, 1986
Restriction of consumption of food	13,800-120,000	Bryansk Oblast, Russia, 1989

Lessons (5/6)

Preventing of ingestion intake of radioiodines by the public (Fukushima accident) is a strong measure for mitigation of the exposure to the thyroid that might have been several orders of higher if an ingestion intake had not been precluded (Chernobyl accident).

Lessons (6/6)

In the intermediate and late phases of the accident the decision on the selection of specific countermeasures should be based on cost-benefit analysis while taking into account the public perception and acceptance of those strategies.

Recommendations (1/2)

1. *Develop and maintain a national strategy of emergency response in case of a large nuclear accident*.
2. *Develop social measures aimed at involving the public in introduction, performance and withdrawal of countermeasures in case of an event, beginning with the decision making process.*
3. *Develop large-scale monitoring capability with attention to minimizing the uncertainty related to the estimate of thyroidal iodine content at the time of measurement.*

Recommendations (2/2)

4. *Following the event, the delay in implementing measures (e.g., individual monitoring, collecting information, etc.) and countermeasures (e.g., sheltering, evacuation, administration of KI) should be as short as possible*.
5. *In the later phases of an emergency, authorities should develop and implement countermeasures that are radiologically justified as well socially acceptable.*
6. *All information and original data that are relevant to the radiological emergency should be collected and archived.*

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