DRAFT
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Draft version of a hypothetical accident scenario
for the EVATECH seminar on May 12 -14

Finnish workshop on clean-up actions for residential areas after a nuclear accident: Accident scenario and background information

FOR TRAINING PURPOSE ONLY

EVATECH project under EC's 5th framework programme

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Introduction

International organisations have been advocating for many years that radiation protection authorities should involve stakeholders (different braches of industry, trade, service, and also the public) in the national planning for protective actions in case of a nuclear accident. Facilitated workshops provide a valuable instrument for this involvement. Within the EVATECH project of the 5th framework programme of the European Commission facilitated workshops are planned in a number of European countries to learn about the practical needs of decision makers and stakeholders. The intention is to improve decision support systems and in particular to shape further their evaluation subsystems. The workshops concentrate on later phase countermeasures for residential areas (EVATECH WP4, Description of work).

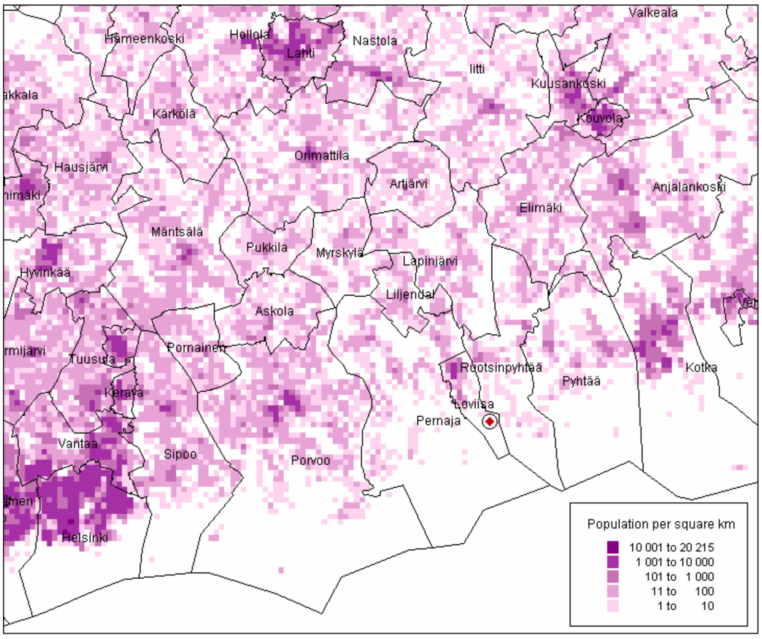
A case study of a hypothetical accident at a national nuclear power plant provides the basis for the workshop, which is arranged seven days after the accident. A variety of stakeholders is invited to broadly evaluate the options that are available a week after the accident to protect the urban population from undue exposure and to clean up urban areas. The underlying accident scenario is presented here.

Accident scenario

An objective of the EVATECH project is to learn from the decisions made in the different participating countries. Since it would be helpful to directly compare the advised intervention strategies, each country uses the same accident scenario and it is strived to have a comparable population distribution in the vicinity of the accident site. In this way the release and dispersion of radioactive material are the same in all participating countries; but the boundary conditions also mean for many countries that the NPP has to be fictitious both in respect to type and other characteristics and in respect to location. In Finland, the site of the Loviisa NPP is chosen, but the reactor is in accordance to the guidelines for the workshops and not the actual one.

Accident site and affected region

The assumed NPP at Loviisa is a PWR with a large, dry steel containment and around 2000 MW(t) power. It is located on a sparsely populated island about 10 km southeast of the city Loviisa. Loviisa with a population of 7,600 is a small town at the southern coast of Finland, about 90 km to the east of Helsinki. Helsinki and surroundings on the other hand are the most densely populated regions in Finland. Other important population centers of the region are Porvoo, Lahti, and Kotka (Fig. 1 and Tab. 1).



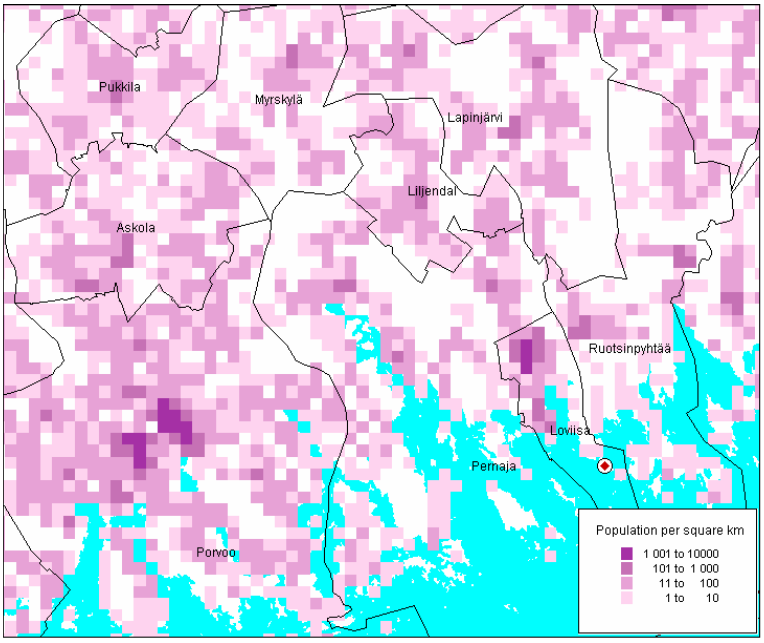


Fig. 1 Municipalities and population distribution of the region (above) and of Loviisa and surroundings (below)

Tab. 1 Population of the municipalities in the region

Municipality	Population	Muncipality	Population
Anjalankoski	18459	Lammi	5886
Artjärvi	1696	Lapinjärvi	3219
Askola	4259	Liljendal	1534
Elimäki	8626	Loviisa	8105
Espoo	177100	Luumäki	5565
Hamina	10012	Myrskylä	2033
Hausjärvi	8027	Mäntsälä	15191
Helsinki	487876	Nastola	15073
Hollola	20074	Nurmijärvi	28946
Hyvinkää	40047	Orimattila	14168

Hämeenkoski	2331	Pernaja	3734
Hämeenlinna	43444	Pornainen	3471
Iitti	7700	Porvoo	45500
Janakkala	15339	Pukkila	1828
Järvenpää	32839	Pyhtää	5434
Kauniainen	8140	Riihimäki	25297
Kerava	28184	Ruotsinpyhtää	3275
Kotka	55731	Sipoo	14978
Kouvola	31875	Tuusula	28050
Kuusankoski	21417	Valkeala	11291
Kärkölä	5304	Vantaa	157156
Lahti	92525	Vehkalahti	12296

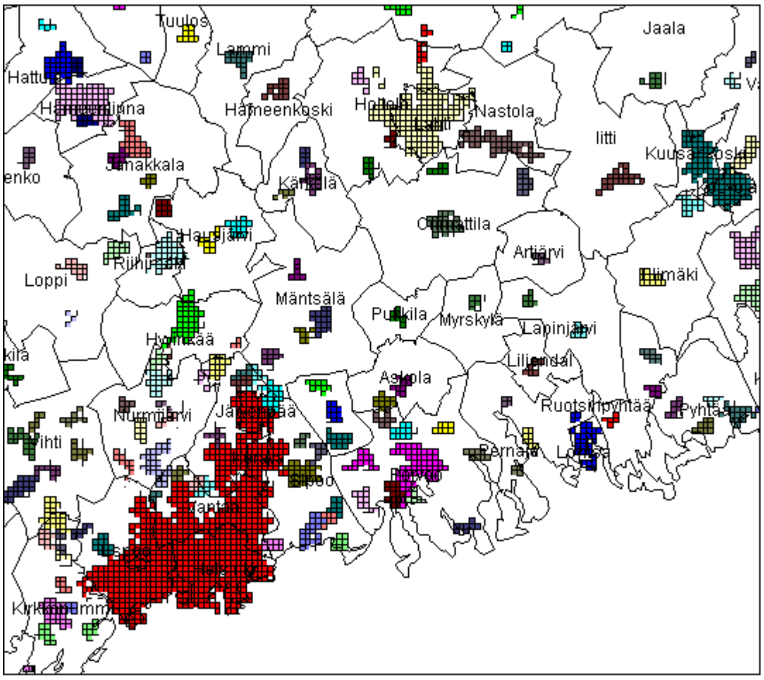


Fig. 2 Population centers of the region. In Finland about 80 percent of the population lives in such urbanized areas.

Events of the accident day

Various decisions are made at different points in time. The narration of the events is kept in the present time in order to facilitate arbitrary entry points into the flow of events.

Wed May 14 00:00 The Radiation and Nuclear Safety Authority (STUK) receives a notification from the operator of the Loviisa nuclear power plant reporting that a fire broke out at 00:00 in the electrical cabinet of reactor 1 and caused the shutdown of the reactor.

01:00 The effects of the fire and an independent failure of the emergency core cooling system prevent core cooling. The containment is isolated. Site emergency is declared.

02:00 The 5-km zone is being evacuated (Fig. 3).

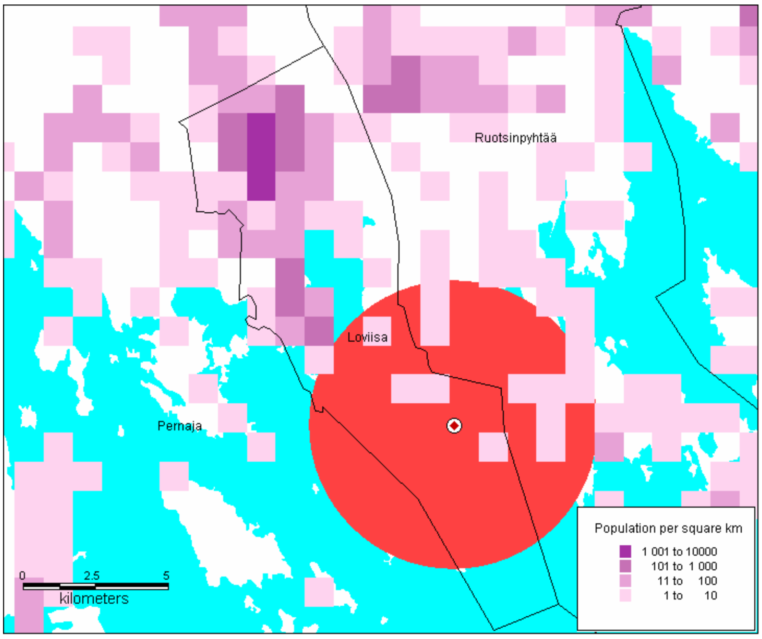


Fig. 3 Five-kilometre zone and population distribution

03:30 The core is heating up. General emergency is declared.

04:30 The vessel breaches at high pressure. Containment sprays are in operation.

07:00 The debris in the cavity cannot be cooled and it reaches a temperature of 2500K.

12:00 The temperature of the debris is stabilized at 1600K. Large amounts of hydrogen and carbon monoxide have been produced.

13:00 Nuclear safety experts are concerned about the prospect of uncontrollable hydrogen combustion within the next few days. They assess the likelihood of different event sequences and provide a probability distribution for the release, if any occurs, according to Tab. 2.

Tab. 2 Probability distributions for the release of different element groups: the 5th, 50th and 95th percentiles are given. The release is stated in fractions of the core inventory for different nuclide groups.

Nuclide group	5th percentile	50th percentile	95th percentile
Noble gases	0.8	0.85	0.93
Iodine total	0.0008	0.013	0.07
Alkaline-group (Cs, Rb)	0.0007	0.01	0.06
Tellurium-group (Te, Se, Sb)	$1 \cdot 10^{-10}$	0.0001	0.02

Alkaline earth-group (Sr, Ba)	$<1\cdot10^{-10}$	$<1\cdot10^{-10}$	$1.5\cdot10^{-6}$
Ruthenium-group (Ru, Mo, Tc)	$<1\cdot10^{-10}$	$<1\cdot10^{-10}$	$5\cdot10^{-8}$
Lanthanide-group La, Nb, Zr, Cm, Ce, Nd, Pm, Sm, Eu, Pu, refr. Ox. Nb, Zr)	$<1\cdot10^{-10}$	$<1\cdot10^{-10}$	$7\cdot10^{-8}$

Wednesday May 14 is cloud-covered over southern Finland with weak winds (2-3 km/h) from south to southeast. The weather forecast promises unchanged conditions for the next day. The Finnish met office reports that the wind will turn in the night thereafter and start to blow from east and northeast, and it will also intensify (6-8 km/h). There will be sporadic rain showers during that night and in the morning hours of the next day. The met office makes the most recent dataset from their numerical weather prediction model available.

15:00 STUK assesses the threat posed to the inhabitants of the region and advises precautionary evacuation of Loviisa (Fig. 3). Information is broadcast on how to shelter in case of a release, and the availability of iodine tablets is ensured.

Thu May 15 19:00 Combustion occurs and the containment fails. Considerable amounts of radionuclides are released to the environment. The wind disperses the released radionuclides towards Loviisa.

The population of Lapinjärvi, Liljendal, Pernaja is urged to shelter and to take iodine tablets (Fig. 4).

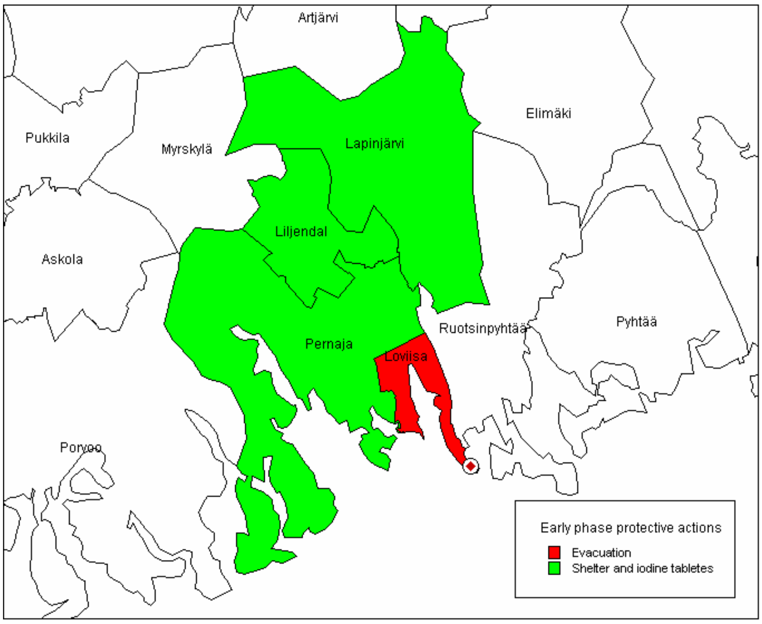


Fig. 4 Early phase protective actions

Fri May 15 07:00 The release-rate has gradually diminished during the last hours and ceased totally at 07:00, 12 hours after start of release. The accident block is under control and no further release is expected.

State of affairs a week later

This section collects what is known a week after the accident about the contamination of the environment, and gives an assessment of the associated health risk. Furthermore it discusses interventions to either reduce the contamination (clean-up actions) or the exposure time (relocate the people to a saver place).

The release happened a week ago, on Thursday, May 15, at 19:00 and caused the contamination of large areas north and west of Loviisa (Fig. 5). It was raining in the region when the plume dispersed over Loviisa, Liljendal and Lapinjärvi. This caused heavy wet deposition (in excess of 100 kBq per square meter for ^{137}Cs) in parts of these municipalities. The deposition was an order of magnitude lower (10 to 100 kBq per square meter for ^{137}Cs) where it was not raining and another magnitude (1 to 10 kBq per square meter) in more distant municipalities of the Uusimaa province.

An expert team worked on a reconstruction of the source term and based on measurements of the fallout and on other sources of information they estimated the actual release of radionuclides according to Tab. 3. They also concluded that the initial intense release rate decreased gradually within 12 hours and that the effective release height was about 100 m.

Tab. 3 Assessment of the actual release. The release is stated in fractions of the core inventory for different nuclide groups.

Nuclide group	Released fractions of the inventory
Noble gases	0.8
Iodine total	0.01
Alkaline-group (Cs, Rb)	0.01
Tellurium-group (Te, Se, Sb)	$1 \cdot 10^{-6}$
Alkaline earth-group (Sr, Ba)	$<1 \cdot 10^{-10}$
Ruthenium-group (Ru, Mo, Tc)	$<1 \cdot 10^{-10}$
Lanthanide-group (La, Nb, Zr, Cm, Ce, Nd, Pm, Sm, Eu, Pu, refr. Ox. Nb, Zr)	$<1 \cdot 10^{-10}$

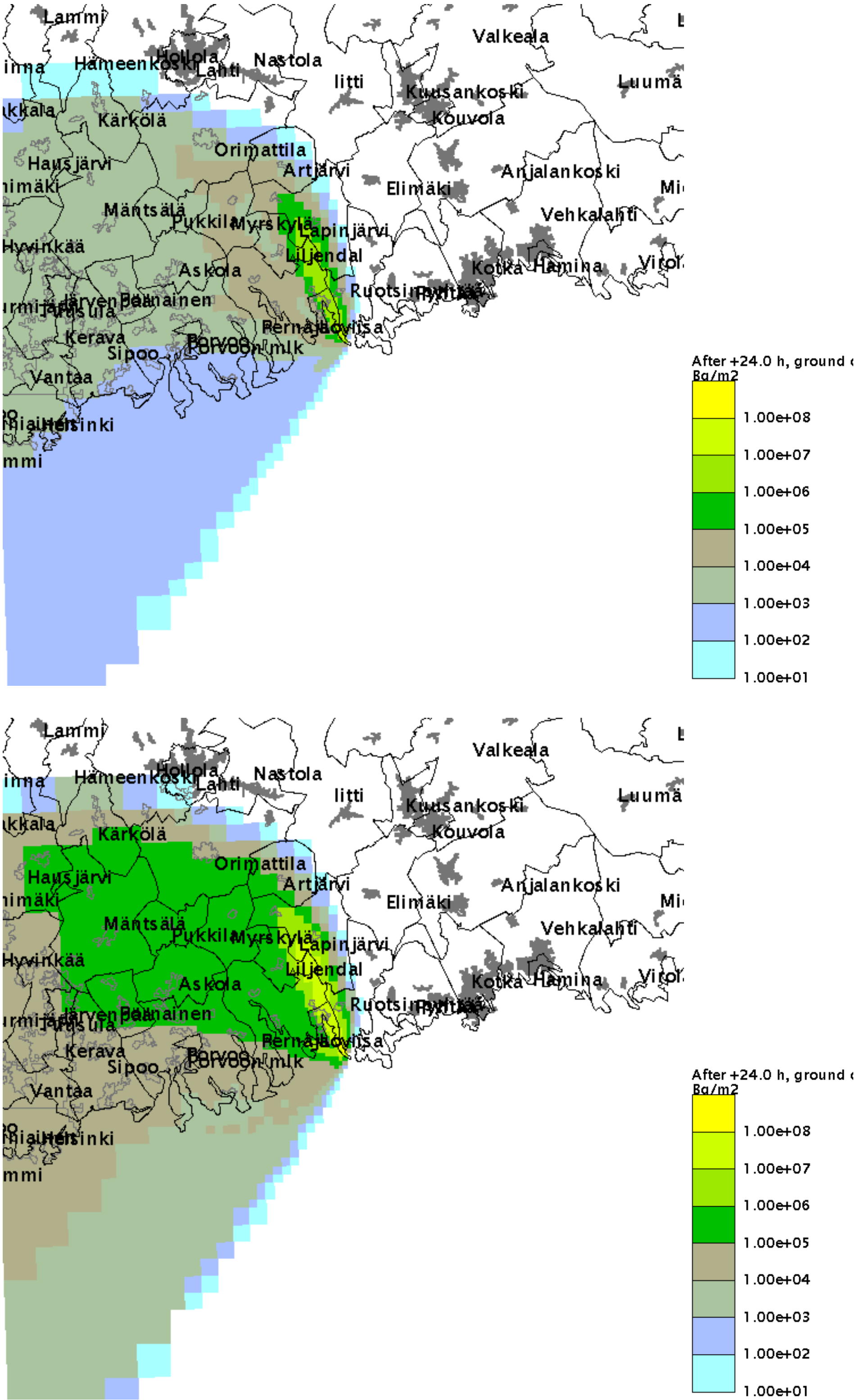


Fig. 5 Deposition of ^{137}Cs (above) and ^{131}I (below)

Received and future doses[1]

A week has passed since the accident. During the passage of the plume the population of the affected areas received a dose directly from the plume, and

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[1] If not mentioned otherwise, doses in this report mean the effective dose to adults in normal-living conditions.

they inhaled radionuclides that accumulate doses throughout the rest of their lives. In Loviisa town these doses would have been up to 1 mSv from the plume and 10 mSv from inhalation. Also ground deposits contributed to the dose. During the first week the dose from this pathway would have been in the order of 10 mSv in Loviisa town, and considerably more towards the accident site (Fig. 6). The population of Loviisa averted these doses because they have been evacuated. In Lapinjärvi and Liljendal, where the population was sheltered and protected by iodine tablets, the corresponding dose would have been in the range from 0.1 to 10 mSv. Also a big share of this dose was averted by protective measures.

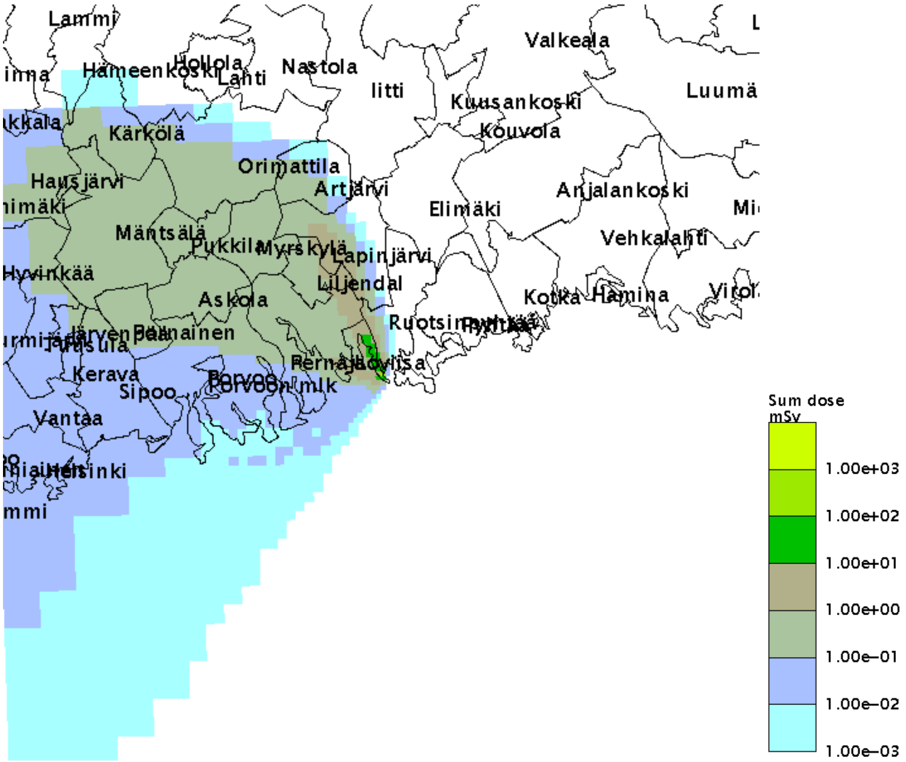


Fig. 6 Effective dose after the first week from (1) external exposure to the plume, (2) internal exposure due to inhaled radionuclides, and (3) seven days of exposure to ground deposits.

The dose of the first week is small compared to the dose expected to accumulate during lifetime, mainly from external exposure to radiation from ground deposits and due to the ingestion of contaminated food. In Loviisa, the dose from ground exposure can reach several hundreds of milliSievert within 50 years, and even exceed 1 Sv closer to the site (Fig. 8).

Next to the irradiation from ground deposits, it is the ingestion of contaminated food that contributes most to the lifetime dose after this accident. For example ^{131}I is found rather soon in the milk which, when consumed, causes a significant burden to the thyroid. But since we are interested here in clean-up actions of residential areas, which do not directly affect the ingestion dose, we do not consider this pathway any further.

An important aspect is the characteristics of the nuclides that were deposited, in particular when and how long they contribute to the dose. At this point in time the noble gases have no significance anymore, because they were not deposited - they only exposed the population during the passage of the plume. The short-lived iodine nuclides contributed considerably in the first days to the external dose, but as time passes there remains mainly radiocaesium. Despite comparable release fractions, ^{131}I was released and deposited (measured in the amount of activity) about ten times more than ^{137}Cs. The decay of short-lived radioiodine (^{131}I has a half-live of 8 days) caused the intense dose-rate of the first days and weeks (Fig. 7). After that there remains long-lived radiocaesium (^{137}Cs has a half-live of thirty years, and ^{134}Cs of two years), which will contribute to the dose over decades. As a matter of fact, the dose from caesium considerably outweighs the dose from iodine (Tab. 4).

Tab. 4 Effective dose (mSv) close to the accident site from ground deposits of ^{131}I, ^{134}Cs and ^{137}Cs, and percentage of the total after 70 years

	7 days		14 days		30 days		1 year		70 years	
I-131	41	1 %	62	2 %	82	3 %	88	3 %	88	3 %
Cs-134	19	1 %	61	2 %	78	3 %	643	21 %	1306	42 %
Cs-137	7	0 %	14	0 %	29	1 %	271	9 %	1685	55 %
Total	66	2 %	137	4 %	189	6 %	1002	33 %	3078	100 %

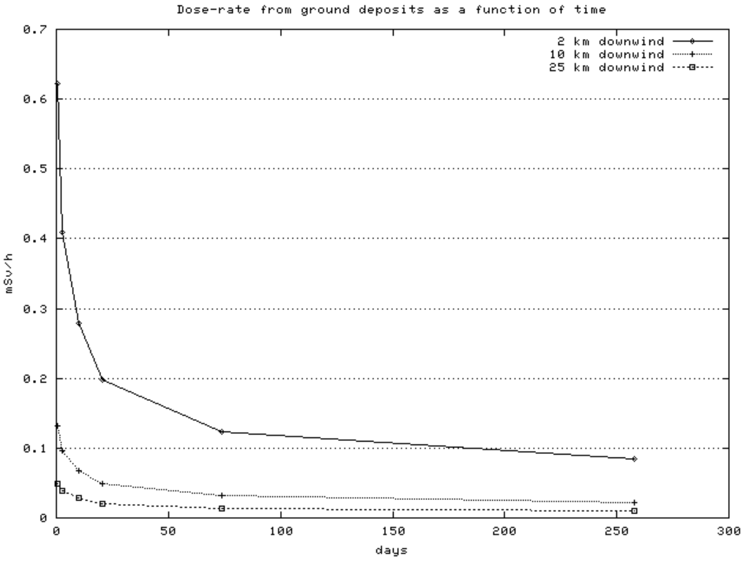
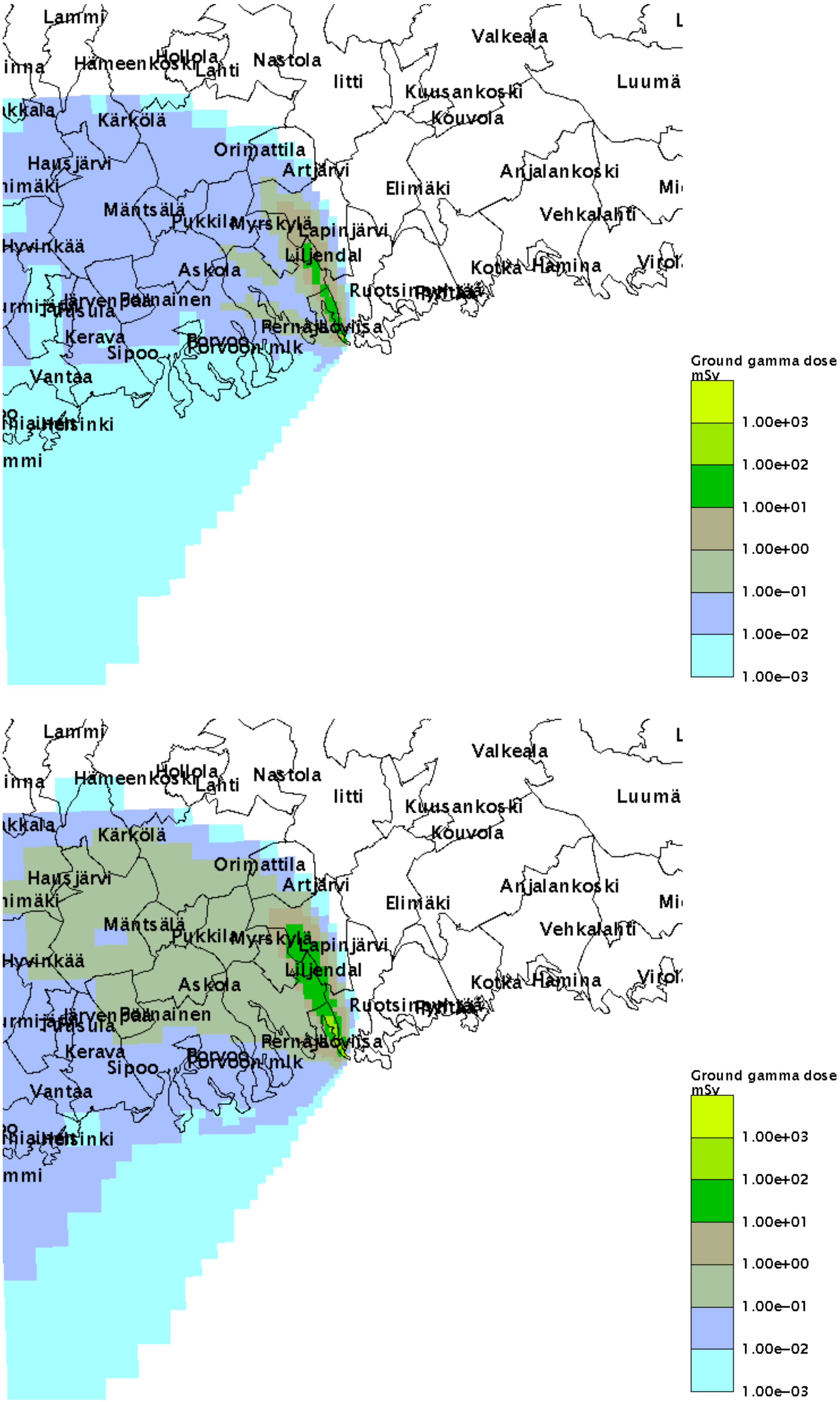


Fig. 7 Measured and predicted effective dose-rates as a function of time at three distances from the accident site.

Consequence assessment and interventions

There is international advice on the need for temporary or permanent relocation. The ICRP reports intervention levels in the range of 5 to 15 mSv averted dose for temporary relocation to be almost always justified, and an intervention level of 1000 mSv in lifetime for permanent resettlement (ICRP Publication 63). Similar advice is given by IAEA: they recommend temporary relocation if 30 mSv in the first month and 10 mSv in a subsequent month can be averted, and permanent resettlement if 1000 mSv can be averted in lifetime (IAEA Safety Series No. 109). These intervention levels were obtained by generic optimisation that balanced the costs of relocation and the achieved dose savings; other, equally important, attributes were not considered. Fig. 8 shows the dose from ground exposure after 30 days, 1 year and 50 years (includes potential exposure during the first week, which has to be kept in mind when comparing with the intervention levels).



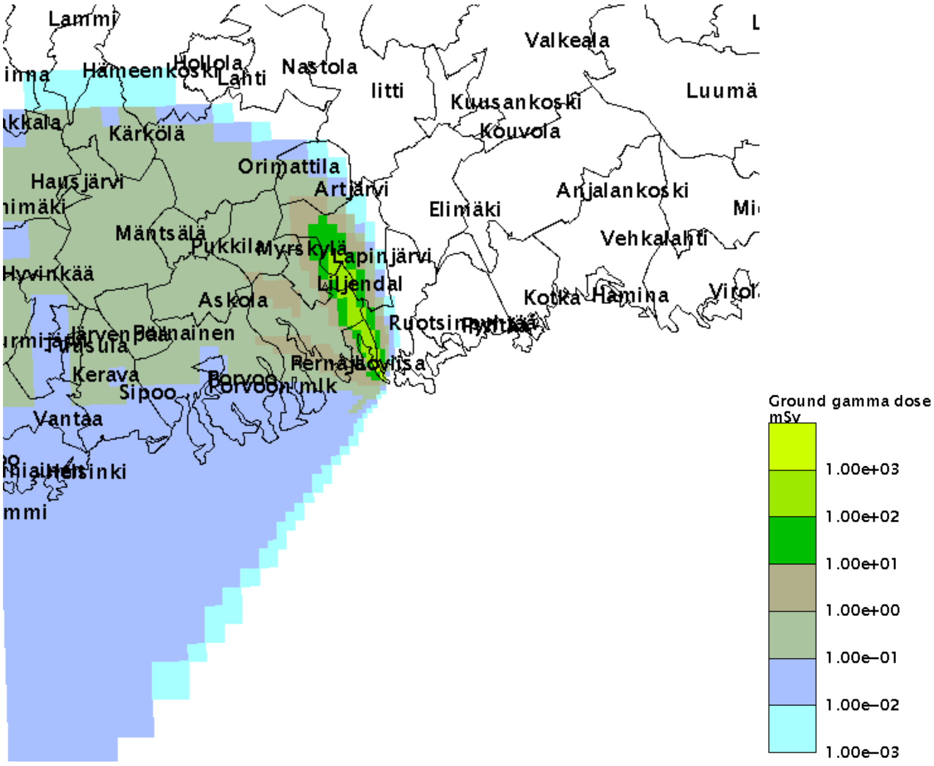


Fig. 8 Effective dose from ground exposure after 30 days (above), 1 year (middle), and 50 years (below).

The population is exposed to radiation from nuclides deposited to different surfaces of their living environment: to indoor surfaces, walls and roofs of the housings, to the garden vegetation, to paved surfaces, and so on. The dose that they receive depends on the amount of radioactivity retained on these surfaces and on the time spent in a specific environment. Clean-up actions remove radionuclides from the surfaces and reduce thus the accumulation of doses. When pondering clean-up actions of the urban environment it is the reduction of this external dose that is in mind.

Computer models and expert judgement were used to assess throughout the affected area the potential consequences of the accident and the effects of countermeasures. For presentation purposes the results are aggregated (summed, averaged) over a small number of regions. Since long-lived ^{137}Cs is the key nuclide in the present case, the contour bands of caesium 137's deposition map (Fig. 5) were used for the subdivision into regions. In practice this subdivision is likely to be adjusted with regard to administrative, geographic and demographic features of the region. In addition, incomplete measurements and unreliable methods might introduce uncertainties into the picture.

Zone 0: Loviisa close to the site

The area close to the site is highly contaminated: ^{137}Cs deposition is in excess of 10 MBq per square meter, dose-rates in the first hours were as high as 600 microSv per hour (which is more than 3000 times the normal background) and lifetime doses would easily exceed 1 Sv. The zone is defined as the area where the ^{137}Cs deposition exceeds 10 MBq per square meter.

Tab. 5 Characteristics

Number of people	17.6
Number of houses	2.7
Avg. Cs-137 deposition (kBq/m2)	16277.8
Avg. Cs-134 deposition (kBq/m2)	16239.0
Avg. I-131 deposition (kBq/m2)	154895.4
Avg. dose in first week (mSv)	43.2
Avg. dose-rate in coming week (uSv/h)	84.1
Avg. dose in coming month (mSv)	45.9
Avg. dose in next 50 years (mSv)	3356.1
Coll. dose in next 50 years (manSv)	57.3
Number of add. cancer deaths	2.9

Tab. 6 Consequences of relocation with different return times

	Day 7 to 14	Day 7 to 30	Day 7 to 90	Day 7 to 182	Day 7 to 365	Permanent
Averted dose per caput (mSv)	14.1	45.9	157.3	307.6	549.8	3356.1
Averted coll. dose (manSv)	0.2	0.8	2.7	5.3	9.4	57.3
Averted number of cancer deaths	0.0	0.0	0.1	0.3	0.5	2.9
Costs (1000 euro)	8.8	24.9	85.5	178.4	363.1	18420.1

Tab. 7 Consequences of different clean-up actions

	Fire hosing pavement	Fire hosing roofs	Fire hosing walls	Vacuum sweeping pavment	Lawn moving	Tree/bush cutting
Averted dose per caput (mSv)	122.3	122.3	195.7	146.8	551.3	69.1
Averted coll. dose (manSv)	2.1	2.1	3.3	2.5	9.4	1.2
Averted number of cancer deaths	0.1	0.1	0.2	0.1	0.5	0.1
Costs (1000 euro)	0.1	0.4	0.1	0.0	0.2	6.0
Coll. dose to workers (manSv)	0.0	0.0	0.0	0.0	0.0	0.0
Decontaminated area (10,000 m2)	0.0	0.0	0.0	0.0	0.3	0.3
Waste (1000 kg)	0.0	0.0	0.0	0.1	0.0	0.1
Work (man-days a 8 hours)	0.3	1.3	0.4	0.0	0.6	27.7

Zone 1: Loviisa, Gislom, and partly Liljendal and Lapinjärvi

The next zone is defined as the area where the ^{137}Cs deposition is in the range of 1 to 10 MBq per square meter. Loviisa, Gislom, and partly Liljendal, and Lapinjärvi lie in this zone.

It was raining when the plume passed through Loviisa, Liljendal, Lapinjärvi, and Pernaja, and this caused considerable wet deposition in these municipalities. In Loviisa town typical values for the caesium deposition are in the range of 1 to 10 MBq per square-meter. The population of Loviisa town has been evacuated. The evacuees, once returned, would receive within the following month a dose from ground exposure in the order of 10 mSv, and during the next 50 years 380 mSv on average.

The caesium deposition also exceeded 1 MBq per square meter in parts of Liljendal, Lapinjärvi, Pernaja (Gislom), but the actual contamination varies considerably throughout these municipalities. Their inhabitants were sheltered during the passage of the plume and the intake of iodine tables protected their thyroid gland from accumulating radioiodine.

Different clean-up actions can be applied to reduce these doses. In addition, the return can be postponed if necessary. Permanent resettlement might be considered as an alternative option. Clean-up actions and relocation may also be combined. In a first approximation, assessments of collective dose, costs, waste, man-hours, etc (Tables below) can be added up to assess the effect of these combined measures.

Tab. 8 Characteristics

Number of people	3031.3
Number of houses	698.9
Avg. Cs-137 deposition (kBq/m2)	2652.6
Avg. Cs-134 deposition (kBq/m2)	2646.3
Avg. I-131 deposition (kBq/m2)	23169.9
Avg. dose in first week (mSv)	4.2
Avg. dose-rate in coming week (uSv/h)	16.7
Avg. dose in coming month (mSv)	7.7
Avg. dose in next 50 years (mSv)	379.6
Coll. dose in next 50 years (manSv)	1123.3
Number of add. cancer deaths	56.2

Tab. 9 Consequences of relocation with different return times

	Day 7 to 14	Day 7 to 30	Day 7 to 90	Day 7 to 182	Day 7 to 365	Permanent
Averted dose per caput (mSv)	2.8	7.7	21.9	40.6	70.1	379.6
Averted coll. dose (manSv)	8.4	23.0	65.1	120.4	207.8	1123.3
Averted number of cancer deaths	0.4	1.1	3.3	6.0	10.4	56.2
Costs (1000 euro)	1533.1	4355.3	14938.6	31166.4	63445.5	3218157.5

Tab. 10 Consequences of different clean-up actions

	Fire hosing pavement	Fire hosing roofs	Fire hosing walls	Vacuum sweeping pavment	Lawn moving	Tree/bush cutting
Averted dose per caput (mSv)	15.3	15.3	21.8	18.4	65.4	7.0
Averted coll. dose (manSv)	45.5	45.5	64.6	54.6	194.2	20.8
Averted number of cancer	2.3	2.3	3.2	2.7	9.7	1.0

deaths						
Costs (1000 euro)	33.8	105.4	35.8	1.5	65.9	1726.2
Coll. dose to workers (manSv)	0.0	0.1	0.0	0.0	0.0	2.0
Decontaminated area (10,000 m^2)	12.1	9.4	12.8	12.1	79.2	79.2
Waste (1000 kg)	0.0	0.0	0.0	24.1	4.8	15.8
Work (man-days a 8 hours)	120.7	376.5	127.8	4.8	158.4	7918.4

Zone 2: Liljendal, Lapinjärvi, Pernaja, Ruotsinpyhtää

The zone is defined as the area where the ^{137}Cs deposition is in the range of 100 to 1000 kBq per square meter. It cuts through Liljendal, Lapinjärvi, Pernaja, and Ruotsinpyhtää.

Tab. 11 Characteristics

Number of people	5151.7
Number of houses	2165.5
Avg. Cs-137 deposition (kBq/m2)	384.7
Avg. Cs-134 deposition (kBq/m2)	383.8
Avg. I-131 deposition (kBq/m2)	3603
Avg. dose in first week (mSv)	1.0
Avg. dose-rate in coming week (uSv/h)	3.7
Avg. dose in coming month (mSv)	1.8
Avg. dose in next 50 years (mSv)	80.5
Coll. dose in next 50 years (manSv)	405.2
Number of add. cancer deaths	20.3

Tab. 12 Consequences of relocation with different return times

	Day 7 to 14	Day 7 to 30	Day 7 to 90	Day 7 to 182	Day 7 to 365	Permanent
Averted dose per caput (mSv)	0.6	1.8	5.5	10.2	17.6	80.5
Averted coll. dose (manSv)	3.2	9.1	27.5	51.5	88.3	405.2
Averted number of cancer deaths	0.2	0.5	1.4	2.6	4.4	20.3
Costs (1000 euro)	2599.0	7383.5	25325.6	52836.6	107559.8	5455773.0

Tab. 13 Consequences of different clean-up actions

	Fire hosing pavement	Fire hosing roofs	Fire hosing walls	Vacuum sweeping pavment	Lawn moving	Tree/bush cutting
Averted dose per caput (mSv)	3.1	3.3	4.2	3.7	13.6	1.6
Averted coll. dose (manSv)	15.5	16.4	21.1	18.6	68.6	7.9
Averted number of cancer deaths	0.8	0.8	1.1	0.9	3.4	0.4
Costs (1000 euro)	115.9	341.4	115.4	5.2	202.7	5312.3
Coll. dose to workers (manSv)	0.0	0.1	0.0	0.0	0.0	1.4
Decontaminated area (10,000 m^2)	41.4	30.5	41.2	41.4	243.7	243.7

Waste (1000 kg)	0.0	0.0	0.0	82.8	14.6	48.7
Work (man-days a 8 hours)	413.8	1219.2	412.1	16.6	487.4	24368.2

Zone 3: Pernaja, Liljendal, Lapinjärvi, Myrskylä, Artjärvi, Orimattila, Ruotsinpyhtää

Large parts of Pernaja, Liljendal, Lapinjärvi, Myskylä, Orimattila, Artjärvi, and Ruotsinpyhtää were contaminated with ^{137}Cs in the range of 10 to 100 kBq per square meter. In these parts there was no rain during the passage of the plume.

Tab. 14 Characteristics

Number of people	12919.5
Number of houses	4132.1
Avg. Cs-137 deposition (kBq/m2)	20.0
Avg. Cs-134 deposition (kBq/m2)	19.9
Avg. I-131 deposition (kBq/m2)	372.2
Avg. dose in first week (mSv)	0.4
Avg. dose-rate in coming week (uSv/h)	0.3
Avg. dose in coming month (mSv)	0.1
Avg. dose in next 50 years (mSv)	6.9
Coll. dose in next 50 years (manSv)	87.1
Number of add. cancer deaths	4.4

Tab. 15 Consequences of relocation with different return times

	Day 7 to 14	Day 7 to 30	Day 7 to 90	Day 7 to 182	Day 7 to 365	Permanent
Averted dose per caput (mSv)	0.1	0.1	0.4	0.8	1.4	6.9
Averted coll. dose (manSv)	0.7	1.9	5.5	10.2	17.5	87.1
Averted number of cancer deaths	0.0	0.1	0.3	0.5	0.9	4.4
Costs (1000 euro)	6473.0	18389.0	63074.4	131591.9	267882.2	13587838.0

Tab. 16 Consequences of different clean-up actions

	Fire hosing pavement	Fire hosing roofs	Fire hosing walls	Vacuum sweeping pavment	Lawn moving	Tree/bush cutting
Averted dose per caput (mSv)	0.3	0.3	0.4	0.3	2.1	0.4
Averted coll. dose (manSv)	3.3	3.5	4.7	4.0	26.6	5.4
Averted number of cancer deaths	0.2	0.2	0.2	0.2	1.3	0.3
Costs (1000 euro)	153.2	593.0	191.2	6.9	373.3	9781.3
Coll. dose to workers (manSv)	0.0	0.0	0.0	0.0	0.0	0.2
Decontaminated area (10,000 m^2)	54.7	52.9	68.3	54.7	448.7	448.7
Waste (1000 kg)	0.0	0.0	0.0	109.4	26.9	89.7
Work (man-days a 8 hours)	547.1	2118.0	682.9	21.9	897.4	44868.5

Zone 4: Rest of the province Uusimaa

There is a very large area that goes up to Helsinki and beyond that is contaminated with ^{137}Cs in the range of 1 to 10 kBq per square meter.

Tab. 17 Characteristics

Number of people	710219.9
Number of houses	95022.2
Avg. Cs-137 deposition (kBq/m2)	3.6
Avg. Cs-134 deposition (kBq/m2)	3.6
Avg. I-131 deposition (kBq/m2)	88.0
Avg. dose in first week (mSv)	0.1
Avg. dose-rate in coming week (uSv/h)	0.0
Avg. dose in coming month (mSv)	0.0
Avg. dose in next 50 years (mSv)	0.3
Coll. dose in next 50 years (manSv)	217.6
Number of add. cancer deaths	10.9

Tab. 18 Consequences of relocation with different return times

	Day 7 to 14	Day 7 to 30	Day 7 to 90	Day 7 to 182	Day 7 to 365	Permanent
Averted dose per caput (mSv)	0.0	0.0	0.0	0.0	0.1	0.3
Averted coll. dose (manSv)	5.8	12.4	22.8	34.8	53.3	217.6
Averted number of cancer deaths	0.3	0.6	1.1	1.7	2.7	10.9
Costs (1000 euro)	365765	1039104	3564125	7435823	15137135	767803648

Tab. 19 Consequences of different clean-up actions

	Fire hosing pavement	Fire hosing roofs	Fire hosing walls	Vacuum sweeping pavment	Lawn moving	Tree/bush cutting
Averted dose per caput (mSv)	0.0	0.0	0.0	0.0	0.2	0.0
Averted coll. dose (manSv)	10.0	11.4	11.7	12.0	123.7	26.0
Averted number of cancer deaths	0.5	0.6	0.6	0.6	6.2	1.3
Costs (1000 euro)	9279.8	17899.0	6910.7	417.6	10307.6	270079.6
Coll. dose to workers (manSv)	0.0	0.0	0.0	0.0	0.0	0.8
Decontaminated area (10,000 m^2)	3314.2	1598.1	2468.1	3314.2	12389.0	12389.0
Waste (1000 kg)	0.0	0.0	0.0	6628.4	743.3	2477.8
Work (man-days a 8 hours)	33142.2	63925.0	24680.9	1325.7	24777.9	1238897.4

Workshop

Intervention strategies

In an accident of this scale it is important to coordinate the response. This is important because resources are limited and not necessarily allocated at the local level. Furthermore, equality of treatment must be guaranteed, i.e. comparable resources must be allocated to avert a cancer case in any single municipality.

As seen above, there are different courses of action that can be taken in the affected areas. There are regions where clean-up actions can make a difference at reasonable costs, there are areas where temporary relocation might be a sensible choice, and there might be an area where resettlement is required. Finally, there are many municipalities where an extra effort is not justified.

Different strategies (alternative courses of action) are thus available and it is up to the participants of the workshop to, first, select the strategies that they want to analyse in more detail and, second, to decide on (or recommend) the strategy that should be implemented. There is not much guidance given here for the first problem and common sense and simple heuristic must do.

Tab. 20 Selected strategies (Example)

Strategy	Zone 1	Zone 2	Zone 3	Zone 4
1	Relocate 1 week Cut grass	Cut grass		
2	Relocate 3 weeks Cut grass	Cut grass		
3	Relocate 1 year Cut grass F. hosing roofs F. hosing walls V. sweep pavem.	Cut grass		
4	Cut grass F. hosing roofs	Cut grass F. hosing roofs		
5	Cut grass F. hosing roofs	Cut grass		
6	Cut grass F. hosing roofs F. hosing walls V. sweep pavem.	Cut grass		

Once a set of viable strategies is selected, it is possible to quantify their ‘hard’ attributes (*averted collective dose*, *number of averted cancer cases*, collective *dose of clean-up workers*, *costs)* from the building blocks of the former section. Some of the formerly presented clean-up actions decontaminate a particular surface (roof or walls, pavements, trees and bushes, or the soil) and can be combined. If more than one action is applied their respective collective dose reductions can, in a first approximation, be added together.

Tab. 21 Consequence table (Example)

Strategy	Averted coll. dose (manSv)	Averted number of cancer deaths	Costs (1000 euro)	Coll. dose to workers (manSv)

1	271	14	1802	0
2	286	14	4624	0
3	635	32	63857	0.1
4	325	16	715	0.2
5	308	15	374	0.1
6	428	21	411	0.1

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Appendix

Clean-up techniques and their applicability

The contribution that each surface makes to the dose depends on various factors: on the type and composition of deposition, living environment and living habits. In general, the major contribution to the lifetime dose (for a fallout containing caesium and in normal living conditions) comes from soil, about 60 - 80% (Brown, MLM, MM). In urban downtown environments (office areas) the main contributors are walls and roofs, 30 - 60%. Following dry deposition the contribution of walls amounts to 10% and hard surfaces about 5%. Walls contribute with 5 - 10% and roofs with about 10%. The lifetime dose from indoor contamination is in general negligible.

Because of wide variety of cleanup techniques and surfaces to be cleaned up, there are several possible ways to perform the decontamination. In developing decontamination strategies one has to know the distribution of the deposited material on different surfaces and the contribution that each surface makes to the dose. Furthermore, one should consider the cost of a technique and its feasibility in terms of availability of equipment and acceptability. Psychological effects and effects on means of earning one's living and on industry are also important. The strategies to be considered could be based on the selection of the surface to be cleaned up, on the choice of a cleanup technique and/or on the width of the area to be cleaned up.

The main aim of the report is study decisions of clean-up actions in urban areas, which can be applied in large-scale accidents and in the early phase. This choice means that the equipments needed in the work have to be available and most likely in common use. The following cleanup techniques to decontaminate various surfaces are selected for further consideration based on this criterion. In Table I is given the percentage dose reduction factors and in the Table II the costs of various cleanup techniques.

Some methods were considered not to be applicable when large areas are contaminated and/or during the first weeks of the accident: peel able coatings, road planning, skim and burial ploughing sand blasting. These techniques were rejected based on the comparison of above-mentioned techniques and on their effectiveness, costs or feasibility.

If no recovery operations are taken, the contamination is left in full in the area. The dose rate will, however, decrease with time through radioactive decay, weathering (e.g., wash off, resuspension and dispersion by vehicle traffic) and through human activities. In wash off ensuing precipitation removes and leaches contamination from surfaces and from the topsoil deeper down. Human activities such as regular cleaning and construction will relocate radionuclides and will in general decrease the dose. Unfortunately, no systematic studies of long-term weathering and the effect of human activities on dose reduction appear to have been carried out.

Roads and pavement

Fire hosing of streets can be done with normal tap water or with tank lorries. In fire hosing as in wash off water removes the contamination from roads and it is accumulated into the drainage system. Dependent on construction of a drainage system the rainwater is either led in the purification system or mixed with the purified sewage. In sewage purification about half of the contamination remains in the sewage sludge and half will be released with the purified sewage. As a result, the contamination is relocated in ditches, rivers, lakes and sees.

The *wet sweeping* or *wet vacuum sweeping* can be carried out with an ordinary broom. If municipal road-cleaning machines (with rotating brushes and vacuum attachment) or just mechanical rotating brooms on tractors are available, it will be possible to sweep the streets much faster and therefore less expensively. Also efficiency would probably be greater. In a series of experiments on a freshly contaminated road wet vacuum sweeping in some cases removed twice as much as through sweeping with an ordinary broom. The efficiency of the method has been found to be greatly dependent on the amount of street dust per square meter. These actions should be implemented within 7 days.

Roofs and walls

In general, *fire hosing* of roofs and walls with tap water pressure removes relatively little activity from building surfaces and has only a minor effect on dose reduction. However, in some cases it could be considered, especially in dry deposition scenarios, in the early phase after an accident and in detached house areas, where the dose reduction has been assessed to be moderate. The efficiency of the method could be improved by using brush in order to remove also organic materials. Other methods, e.g., sandblasting and ion exchange are generally expensive and the dose reduction factors are found to be low in urban area.

High-pressure water treatment (through a turbo nozzle) could also be used for decontamination of roofs and walls. The efficiency of this technique has been found to be greater in the early phase after deposition, presumably due to the time-dependent fixation of the caesium ion in the structure of materials. In experiments with freshly contaminated bricks and tiles it was found that the contamination was so loosely bound on the surface that much of it could be easily removed by simply spraying with water (xx). Therefore, it may not be necessary to use the water with high pressure in the early phase (first week).

The problem with hosing is the control of water, which could contaminate the soil around buildings and thus increase the dose rate. The most contaminated soil has to be removed.

The water hosing method for roofs and walls suggested for use immediately after deposition is simply fire hosing through an ordinary nozzle. The action should be implemented within 7 days.

Lawn

Grass is cut normally but preferably using a cutter with a grass collector. If a collector is not available, the cut grass has to be raked up. However, hand raking in large areas is not feasible. The cut grass is subsequently collected and buried at a controlled disposal site. Done within few days after dry deposition grass cutting is effective in reducing dose. The transfer process of caesium contamination from grass to soil has been found to have a half-life of about 15 days. It is also a cheap method and because population could do it by themselves it will lessen anxiety.

The grass cutting to reduce the radiation dose is effective in dry deposition situation and done within two weeks. After a few weeks it would be useless. The method could also be considered in wet fallout situations.

Trees and bushes

In addition to grass, trees and bushes are effective interceptors of airborne particles and by removing trees and bushes in the vicinity of buildings the dose will be reduced very efficiently, but only in the first years. It is assumed that branches of deciduous trees are cut off and conifer trees are felled. The resulting amount of waste can be substantial. A part of the contamination also migrates into the wood tissue. Leaves have to be collected and disposed in the fall.

The pruning or felling down trees to reduce the radiation dose is effective in dry deposition situation and done in the first month. After the first year it would be useless. The plant and bush removal should be implemented within 7 days.

Soil

Since the downward migration of caesium is slow, *scraping the topsoil* will be effective for years after the fallout. Scraping of soil, about 5 cm is assumed to be carried out using spade in small scale and a bulldozer, grader, front loader or some such machinery in large areas. The problem with scraping of soil is the generation of large amounts of waste. If fertile soil or/and vegetation is removed the method include also reconstruction of land and planting of vegetation.

Covering the contamination with clean soil, concrete or asphalt is most applicable in small scale and whether ameliorate of soil is also thought over. Covering the contamination with clean soil and scraping the topsoil are applicable independent of type of fallout and time since accident.

With *rotovating* the contamination is mixed into the upper 10 - 15 cm soil but using digging and ploughing the contamination is relocated somewhat deeper in soil. Digging could be considered in small scale and ploughing and rotovating in large urban areas, like in open parks. In deep-ploughing the soil is turned up to 45 cm whereas with an ordinary plough to about 25 cm. In digging and ploughing no waste is generated. An especially advantageous solution would be the application of the specially constructed skim-and burial plough, which has approximately the same dose reducing effect as deep ploughing, but leaves the soil quality unaffected. The efficiency of these procedures will depend greatly on the soil type. In stony soil and areas having dense vegetation the methods are not feasible.

Selected attributes

Averted collective dose

Averted dose per caput

Collective dose to clean-up workers

Costs

Waste disposal

Models for dose assessment, cost and resource quantification

This appendix documents the models that were used for dose assessment, cost and resource quantification and compiles the parameters that were used in the calculations. Parameters were, when available, taken from Andersson (1996), which addresses clean-up actions for ^{137}Cs-contaminated residential areas.

Dose conversion factors are usually reported in the literature for a given activity deposition to lawn. For ^{137}Cs the values of Tab A.1 were used, which express the effective lifetime dose that is received by the inhabitants of different dwellings in a situation where the deposition to lawn is 1 MBq per square meter. Such house-type and deposition mode dependent values were not available for ^{131}I and ^{134}Cs, and dose conversion factors from GSF were used (Tab. A.2). In addition, the GSF-factors contain integration time information that is not provided by Andersson. Tables A.1 and A.2 were merged to obtain integration time dependent dose conversion factors that also account for house-type and deposition mode. These dose conversion factors were used to calculate the dose after 7, 30, 90, 180, 365 days, and 50 years. The resulting dose was summed over deposition mode and averaged over house-type.

An additional data source was the number of people per square-kilometre living in different dwellings: in detached and semi-detached houses, multi-storey blocks and other house types (Statistic Finland, 1992). This information was used to calculate the collective dose and the house-type averaged dose per caput within each grid cell. The population of the region lives predominately in *detached wooden houses*.

Tab. A.1 House-type and deposition mode dependent effective lifetime dose from a ^{137}Cs deposition to lawn of 1 MBq/m^2 (Source: Andersson, 1996)

Nuclide	Detached wooden house		Detached brick house		Semi-detached house		Terrace house		Multi-storey block	
	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet
Cs-137	186	170	121	111	70	64	42	37	33	29

Tab. A.2 Dose (effective, adults) conversion factors for ground exposure as a function of integration time (Source: GSF)

Time (days)	I-131	Cs-134	Cs-137
7	1.62E-10	7.82E-10	2.89E-10
14	2.49E-10	2.55E-09	5.73E-10
30	3.27E-10	3.24E-09	1.21E-09
365	3.52E-10	2.68E-08	1.13E-08
18250[a]	3.52E-10	5.44E-08	6.75E-08

[a] 50 years

Avertable doses of clean-up actions were calculated by applying dose reduction factors (Tab. A.3). The doses avertable by temporary relocation of different durations were, given the doses for different integration times, straightforwardly to obtain.

In calculating the collective dose to workers, it was assumed that the exposure happens during the coming week, i.e. the average dose-rate during that week was taken and multiplied by the man-hours needed for the cleaning-up. A factor of 2 was introduced to account for open-air conditions.

Tab. A.3 Dose reduction (in percents of the effective lifetime dose) through clean-up actions in case of dry and wet deposition of ^{137}Cs (Source: adapted from Andersson, 1996)

Action	Detached wooden house		Detached brick house		Semi-detached house		Terrace house		Multi-storey block	
	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet
F. hosing roads	5	5	5	5	5	5	5	5	8	13
F. hosing roof	5	5	8	8	10	8	6	4	1	1
F. hosing walls	8	8	4	4	2	2	2	2	3	3
V. sweeping roads	6	6	6	6	6	6	6	6	7	15
Cutting grass	60	20	55	20	68	20	65	20	69	20
Pruning trees	15	2	15	2	11	2	9	1	6	1

A simple unit cost approach was used for the cost and resource assessment. The unit was the square-meter and multiplication with the size of the relevant areas (Tab. A.4) gave the desired endpoints. The number of different housing forms per square kilometre (Statistics Finland, 1992) was used to calculate the house-type averaged decontamination area in each square kilometre of the computation grid.

Tab. A.4 Areas (in square-meter) that are associated with clean-up actions (Source: adapted from Moring and Markkula, 1997)

Action	Detached wooden house	Detached brick house	Semi-detached house	Terrace house	Multi-storey block
F. hosing roads	100	100	700	2000	2000
F. hosing roof	120	120	300	450	450
F. hosing walls	150	150	400	1000	1000
V. sweeping roads	100	100	700	2000	2000
Cutting grass	1050	1050	1050	3400	20
Pruning trees	1050	1050	1050	3400	20

For clean-up actions the costs of *work*, *equipment*, and *waste* were considered (Tab. A.5). The equipment cost only includes consumables (fuel) and neither rent nor capital costs for the investment.

Hasemann (2000) was used as data source for relocation. Fifty euro per caput and direction were assumed for *transportation*, 1,970 euro per caput-year for *accommodation*, and 19,610 per caput-year for *loss of income*. Costs for *non-*

residential capital, *houses and buildings*, *consumer durables*, and *land*, which are also reported in Hasemann, were not included.

Tab. A.5 Costs of clean-up actions in euro per square-meter (Source: adapted from Andersson, 1996)

Action	Work	Equipment	Waste
F. hosing roads	0.2000	0.0800	0.0000
F. hosing roof	0.8000	0.3200	0.0000
F. hosing walls	0.2000	0.0800	0.0000
V. sweeping roads	0.0080	0.0016	0.0030
Cutting grass	0.0400	0.0032	0.0400
Pruning trees	2.0000	0.0800	0.1000

The amount of waste that has to be dealt with, and the man-hours needed were calculated by means of the parameters of Tab. A.6. Liquid waste that is produced by fire hosing was assumed to be uncontrolled, and was excluded both from the resources table and costs table.

Tab. A.6 Other resources (Source: adapted from Andersson, 1996)

Action	Amount of waste (kg/m2)	Man-hours per square-meter
F. hosing roads	0.0000	0.0080
F. hosing roof	0.0000	0.0320
F. hosing walls	0.0000	0.0080
V. sweeping roads	0.2000	0.0003
Cutting grass	0.0060	0.0016
Pruning trees	0.0200	0.0800

The final operation in the assessment calculations was data aggregation. As mentioned in the text, the contour bands of ^{137}Cs were used in this data reduction operation. Collective dose, costs, man-hours, and waste could all be added within the zones of similar caesium contamination. For other endpoints, e.g. dose, the population-weighted average was calculated.

Model output