A COMPARISON OF REMEDIATION AFTER THE CHERNOBYL AND FUKUSHIMA DAIICHI ACCIDENTS

B.J Howard

S. Fesenko

M. Balonov

G. Pröhl

S. Nakayama

For the first five years after both accidents
(but not the emergency phase)

Centre for Ecology & Hydrology
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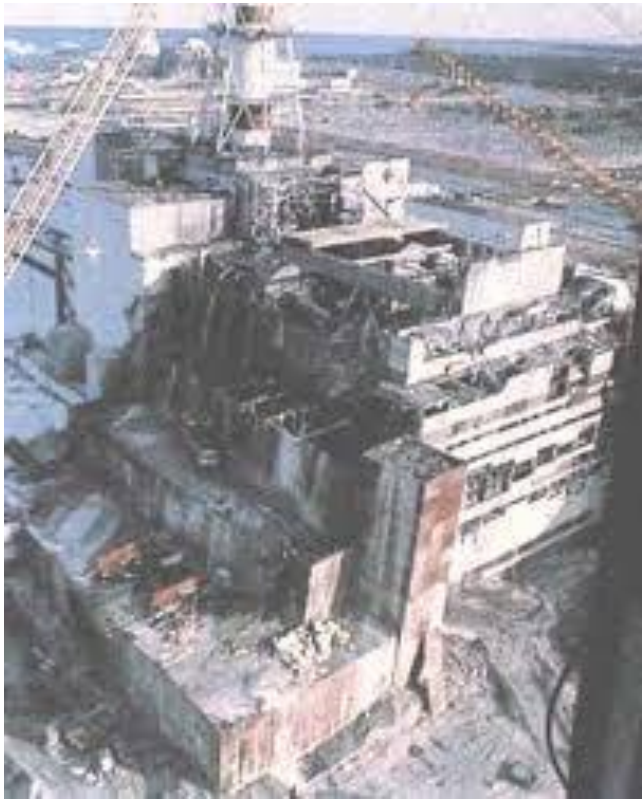
The accidents: Chernobyl USSR, 1986

- Unit 4
- Atmospheric release (PBq)
  - ^{131}I - 1760; ^{134}Cs ~ 47, ^{137}Cs ~ 85; ^{90}Sr – 10
- Release pattern
  - Initial release with the thermal elevation; 10-day variable releases due to fire
- Atmospheric conditions
  - Variable wind direction; Complex multi-directional land deposition (dry and wet)



The accidents: Fukushima Daiichi, Japan, 2011

- Several Units
- Atmospheric release (PBq)
  - ^{131}I - 160; ^{134}Cs and ^{137}Cs ~12-16
- Release pattern
  - Several initial releases due to venting and hydrogen explosions;
  - Weeks of releases
- Atmospheric conditions
  - Variable wind direction; Dispersion toward the ocean (east) and only *small fraction* was to land;
  - Dry and wet deposition (incl. snow); Land deposition prevails in the north-west direction

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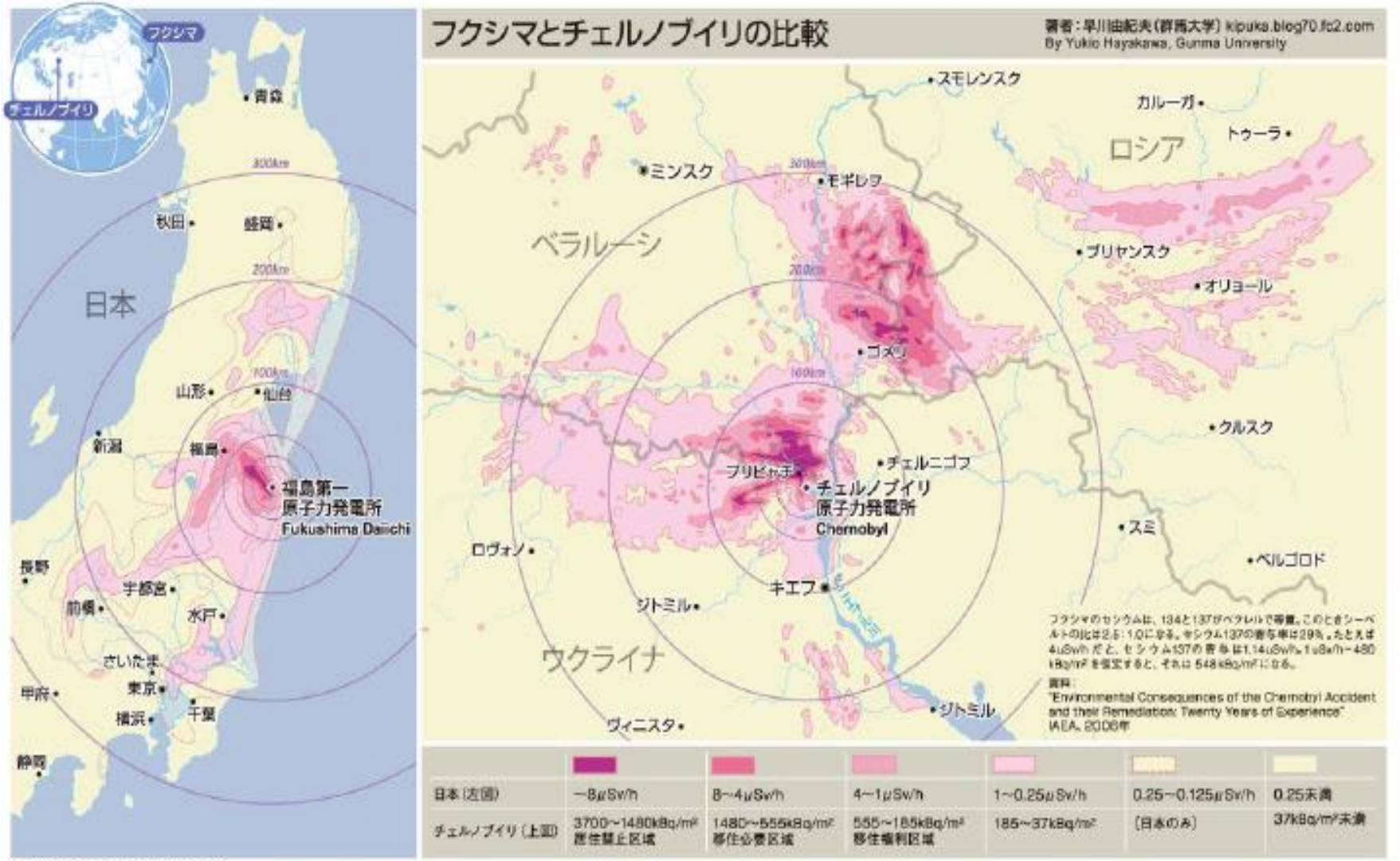
Comparison of ground deposition ^{134}Cs & ^{137}Cs

Accident	Deposition to terrestrial and freshwater systems and affected areas			
	^{137}Cs		^{134}Cs	
	Total deposition to terrestrial and freshwater systems (PBq)	Area with deposition > 100 kBq/m^2 (km^2)	Total deposition to terrestrial and freshwater systems (PBq)	Area with deposition > 100 kBq/m^2 (km^2)
Chernobyl	64 (Europe)	56000	35 (Europe)	~30000
Fukushima Daiichi	2-3 (Japan)	~3000	2-3 (Japan)	~3000
Chernobyl/ Fukushima Daiichi		~20		~10

IAEA 2006 Chernobyl forum; Morino 2011 Geophys. Res. Lett. 38; Yasunari 2011 PNAS 108

The key affected areas



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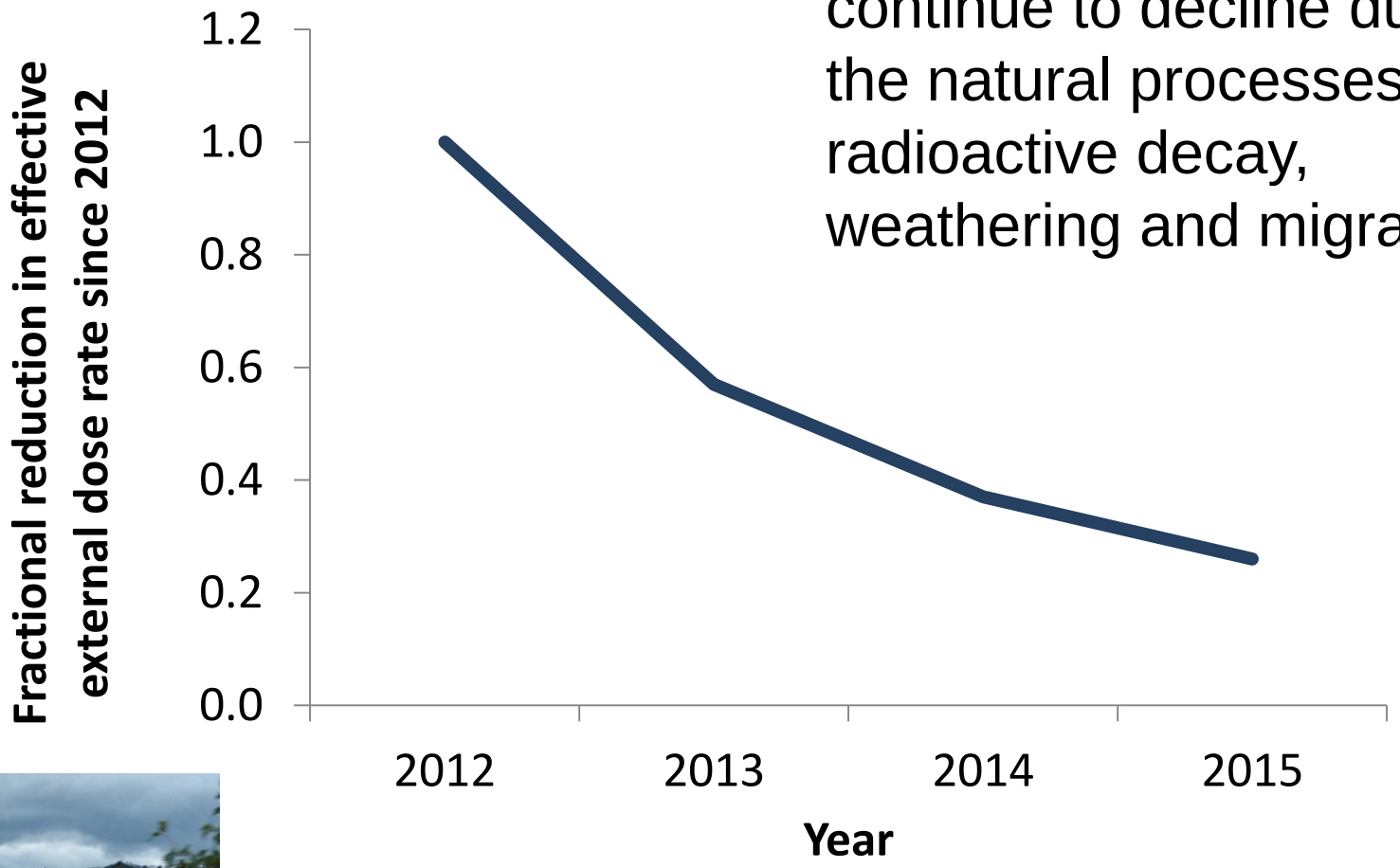
Comparison of the contaminated areas

Factor	Chernobyl	Fukushima Daiichi
Timing	At start of growing season	Before growing season
Population intensity	Moderate, no pressure to use land	High, pressure on available land
Terrain	Flat, forested and agricultural	Mountainous: forested slopes and coastal catchments
Intensity of agriculture	Low - medium	High
Key products	Milk, meat, grain, potatoes	Rice, fruit, leafy and root crops, grain, flowers
Lateral movement across landscape	Low	Potentially high

Change in external dose with time



Gamma dose rates continue to decline due to the natural processes of radioactive decay, weathering and migration

IAEA Fukushima Report - Technical volume 5/5 p 21

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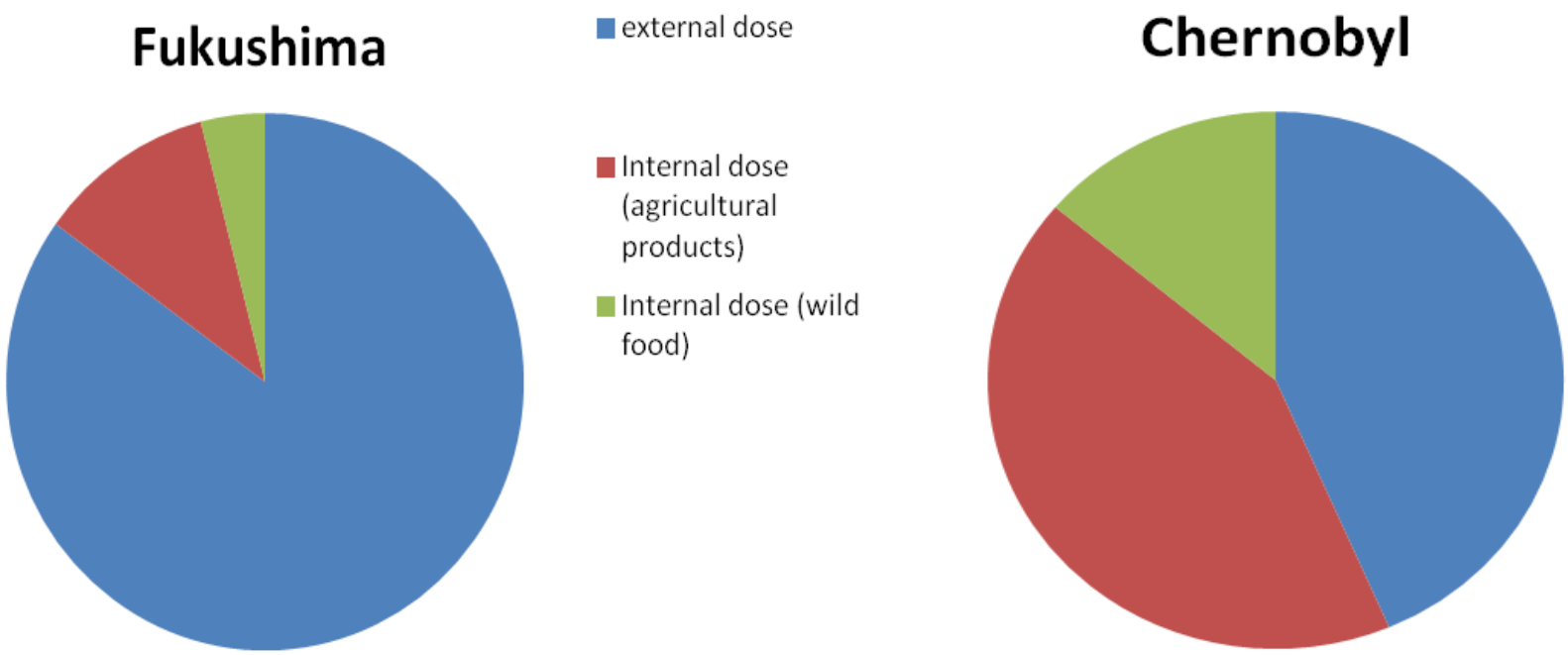
Comparison of internal exposure pathways

Factor	Chernobyl	Fukushima Daiichi
Fraction of soils with high OM content	Moderate to High	Low
K fertiliser usage	Very low to moderate	High
Radiocaesium availability for root uptake	Moderate to very high	Very low to moderate
Transfer to animal products	Moderate to High	Low
Intake of local food	High to very high	Low
Intake of wild food	Moderate to very high	Low to moderate

Comparison of site specific contribution to dose



Contributions of ingestion for both Chernobyl and Fukushima vary widely, in particular for Chernobyl

Fukushima data for Kawauchi Village, Fukushima Prefecture [Taira et al., 2014] . Chernobyl: Average data for selected rural settlements affected by the Chernobyl accident [Jacob et al., 2001]

Affected landscapes – focus of remediation

Chernobyl

Collective and private farming, agriculture, forests, uplands

Fukushima Daiichi

Decision to remediate evacuated areas

Importance of rice production in paddy fields

Forested catchments with steep slopes

Goals of recovery

Reduction of dose - long term goal <1mSv/y at both sites

To enable residents of contaminated areas to return to a normal life

CHERNOBYL

- Some hundred of thousands of people were living in areas with > 1 mSv/y
  - Need to remediate to reduce their effective dose rate
  - Secondary concern to return people to evacuated areas

FUKUSHIMA DAIICHI

- To re-establish an acceptable basis for a fully functioning society in all affected areas
  - Revitalisation of all contaminated areas

Food standard limits – Chernobyl and Fukushima

	Food Standard Limits Bq/kg fw				
	Chernobyl			Fukushima	
Date implemented	30.05.1986	15.12.1987	22.01.1991	17.03.2011©	1.04.2012
Estimated annual effective dose (mSv)	<50	<8	<5	< 5	<1
Food category					
General food				500	100
Meat and meat products	3700	1850-3000	740		
Eggs	37000	1850	740		
Fish	3700	1850	740		
Vegetables		740	600		
Bread	370	370	370		
Dairy products	370-18500	370-1850	370-1850		
Cattle milk/infant food					50
Milk	370-3700	370	370	200	
Drinking water				200	10

Remediation Action Levels

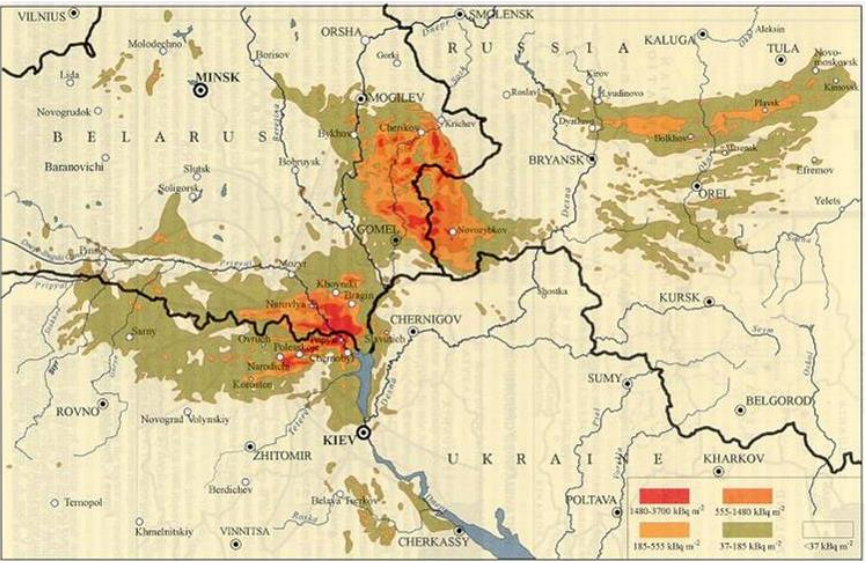
- Specific actions applied to reduce environmental contamination and radiation doses to people guided by derived ‘remediation action levels’.
- Radiological criteria
  - Dose cannot be easily measured, so “operational easily measurable quantities” are derived
  - ambient gamma dose rates (µSv/h)
  - deposited activity per unit area (Bq/m^2)
- Derived using models and assumptions about living habits and about environmental behaviour of radionuclides.

Comparison of radiological criteria

Factor	Chernobyl	Fukushima Daiichi
	Similarities	
	Long term goal of effective annual dose 1 mSv	
	Differences	
Temporary permissible levels for effective annual dose	1986 – 100mSv 1987 – 30 mSv 1988- 1989 – 25 mSv 1991- 1mSv	March 2011 – 5 mSv Sep 2011 - 1 mSv
Ambient dose rate µSv/h	2.2 corresponding to lifetime additional dose of 350 mSv (applied in 1989)	0.19 (excl. natural background) corresponding to annual additional dose of 1 mSv
Changes with time in food standard limits	Down in CIS countries, stable in EU countries	Down (decreasing)

0.19 µSv/h is about 50 kBq m^{-2} of ^{137}Cs and about 20 kBq m^{-2} ^{134}Cs

Chernobyl designation of remediation areas



^{137}Cs kBq/m^2	Designation
Below 37	Not contaminated
37 - 185	Remediation for areas with “sensitive soils” (eg. wet peat, acid sandy)
185 - 555	Remediation applied for sandy soils and light loam soils
555 - 1480	Full scale remediation
>1480	No economic activity

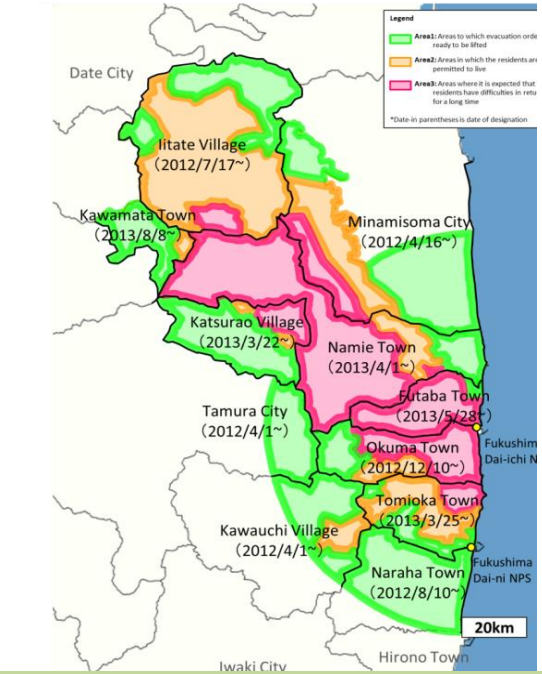
Set definition of contaminated land at 37kBq/m^2

Identified settlements where annual dose rate was > 1 mSv.

Izrael 1990

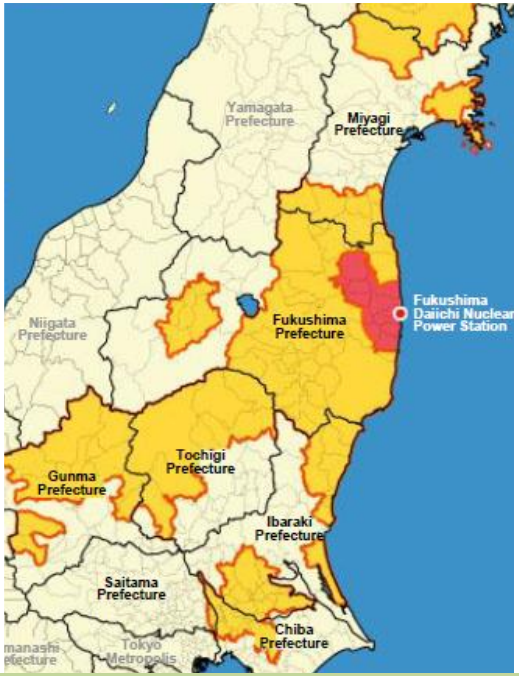
Fukushima designation of remediation areas

Special Decontamination Area (SDA) (Evacuated areas)



Coloured areas were remediated

Intensive Contamination Survey Area (ICSA) (Not evacuated areas)



SDA 1 (Green) : additional exposure rate lower than 20 mSv/year (Evacuation orders are ready to be lifted)

SDA 2 (Yellow): additional exposure rate between 20-50 mSv/year (Residents are not permitted to live)

SDA 3 (Red): additional exposure rate higher than 50 mSv/year (Residents have difficulties in returning for a long time)

ICSA: additional exposure rate higher than 1 mSv/year

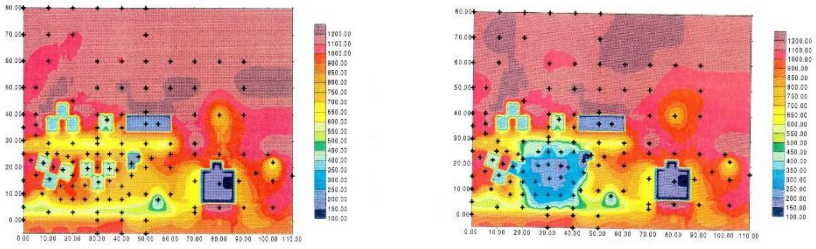
Comparison of remediation approach

Aspect	Chernobyl	Fukushima Daiichi
	Similarities	
	Restrictions and food monitoring	
Radiological Criteria	Food standards, [RCs] soil, ambient dose rate	
	Decontamination of residential areas	
	Differences	
Key focus	External and internal dose	External dose
Remediated areas	All settlements with average individual dose > 1 mSv/y	ICSA and evacuated areas - SDA 1,2,3
Approach	Risk based - averted dose, optimisation taking account of cost-benefit	Rapid implementation, optimisation, social and cultural influence, sufficient financial resources available, high priority on dose reduction - even in less affected areas
Cost	High	Very high
Forest	Optimisation, advice	Border decontamination

Decontamination Of Residential Areas

Removal of topsoil (5 cm) and surface deposits from houses, gardens, roads

Chernobyl



Dose rate map of a settlement before and after decontamination (nSv/h)

Fukushima Daiichi

Effectiveness of reduction of the external ambient dose rate :

- 5-10 fold for early removal of surface deposits.
- 2-4 fold reduction thereafter

Remedial measures applied - residential

Remediation measure	Chernobyl	Fukushima Daiichi
Decontamination of residential areas		
High pressure water hosing	✓	✓
Removal of deposits from the roof, gutters etc.	✓	✓
Wiping roofs and walls	✓	✓
Vacuum sanding		✓
Topsoil removal	✓	✓
Removal of plants	✓	✓
Removal of deposits in road ditches		✓
Decontamination of gardens/trees		
Topsoil removal		✓
Paring fruit trees		✓
High pressure water hosing		✓
Mowing		✓
Removing leaves	✓	✓

Fukushima: environmental remediation

Farmland Pilot Projects

- Removal of 4 cm of topsoil (4cm)
- Removal of topsoil using soil hardener (2 cm)
- Removal of grass and upper root-top soil layer (3 cm) (for meadows).
- Deep ploughing
- Draining suspended soil from paddies

Testing top soil removal after using soil hardener
(Courtesy from MAFF-JAEA-NARO)

Comparison of agriculture remediation measures

Remediation measure	Chernobyl	Fukushima Daiichi
Remediation for animal products		
Clean feeding	✓	✓
AFCF to animals	✓	
Live monitoring of domestic animals	✓	
Remediation of agricultural land		
Radical improvement – ploughing, reseeding, additional fertilisation	✓	
Soil removal		✓
Tillage reversal		✓
Soil treatment with additional K and P	✓	✓
Soil amendment with liming	✓	
Application of sorbents and organic fertilisers	✓	
Drainage of wet peats	✓	
Paddy fields puddling and removal of suspended sediment		✓
Removal of plants		✓
Soil hardening and removal		✓

Agricultural remediation - developments

Chernobyl

- Clean feeding
  - Biological half lives
- Live monitoring
- Cs binders
- Radical improvement

Fukushima Daiichi

- Removal of plants, topsoil
  - soil hardener
- Draining suspended soil from paddies
- Deep ploughing
- Treatment with extra K

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Remediation of farmland - Fukushima

APPLICABILITY OF REMEDIATION MEASURES FOR FARMLAND (MAFF 2014)

Remediation measure	Radiocaesium activity concentration in soil (Bq/kg)			
	< 5000	5000-10000	10000-25000	>25000
Enhanced use of K-fertilizer to reduce Cs-134/137 uptake				
Reversal tillage to bury Cs-13/137 (fields, rice paddies, grassland)				
Soil suspension in water and removal with extracted water (rice paddies)				
Top soil removal (fields, rice paddies, grassland)				
Using an agent to solidify the soil to allow removal of radiocaesium from surface soil				
Weed / Grass / pasture removal				

Forest remediation

- Restrictions on
  - access, harvesting of food products, collection of firewood
- Local monitoring

Chernobyl

- Optimisation approach

Site specific settlement information on:

- Spatial variation in contamination
- Which mushroom species to avoid
- Where and when to collect wood, wild products and hunt game animals
- Tree felling schedules

Fukushima Daiichi

- Remove surface material from 20 m border
- Action level for use of wood for mushroom production
- Decision not to implement additional measures

Waste generation and management

Chernobyl

- Decontamination of ca. 1000 settlements and waste buried nearby
- Selection of remediation options which did not generate waste

Fukushima

- Decontaminating ICSA and SDA
- Huge generation of waste
- High costs

Conclusions

- For both accidents, **the long term goal of remediation is an individual additional annual effective dose of 1 mSv**.
- The radiological consequences of the Fukushima Daiichi accident for the public is much lower than that of Chernobyl, but the **scale of remediation activities is comparable**
  - Radiological criteria for remediation applied in Japan are lower than those applied in the USSR, and have therefore had relatively higher associated costs
  - adoption of lower standard limits for food and other remediation action levels in Japan
  - decision to remediate evacuated land in Japan
- After Chernobyl **weighting of averted dose versus remediation costs** was an important part of the remediation strategy. In Japan remediation of affected districts was **justified and implemented based on radiological and/or social and cultural considerations**.