A comparison of remediation measures applied after the accidents in the Chernobyl and Fukushima Daiichi NPPs

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The basis of this presentations is a presentation given at the IRPA congress in 2016
Thank you to the co-authors

- A COMPARISON OF REMEDIATION AFTER THE CHERNOBYL AND FUKUSHIMA DAIICHI ACCIDENTS

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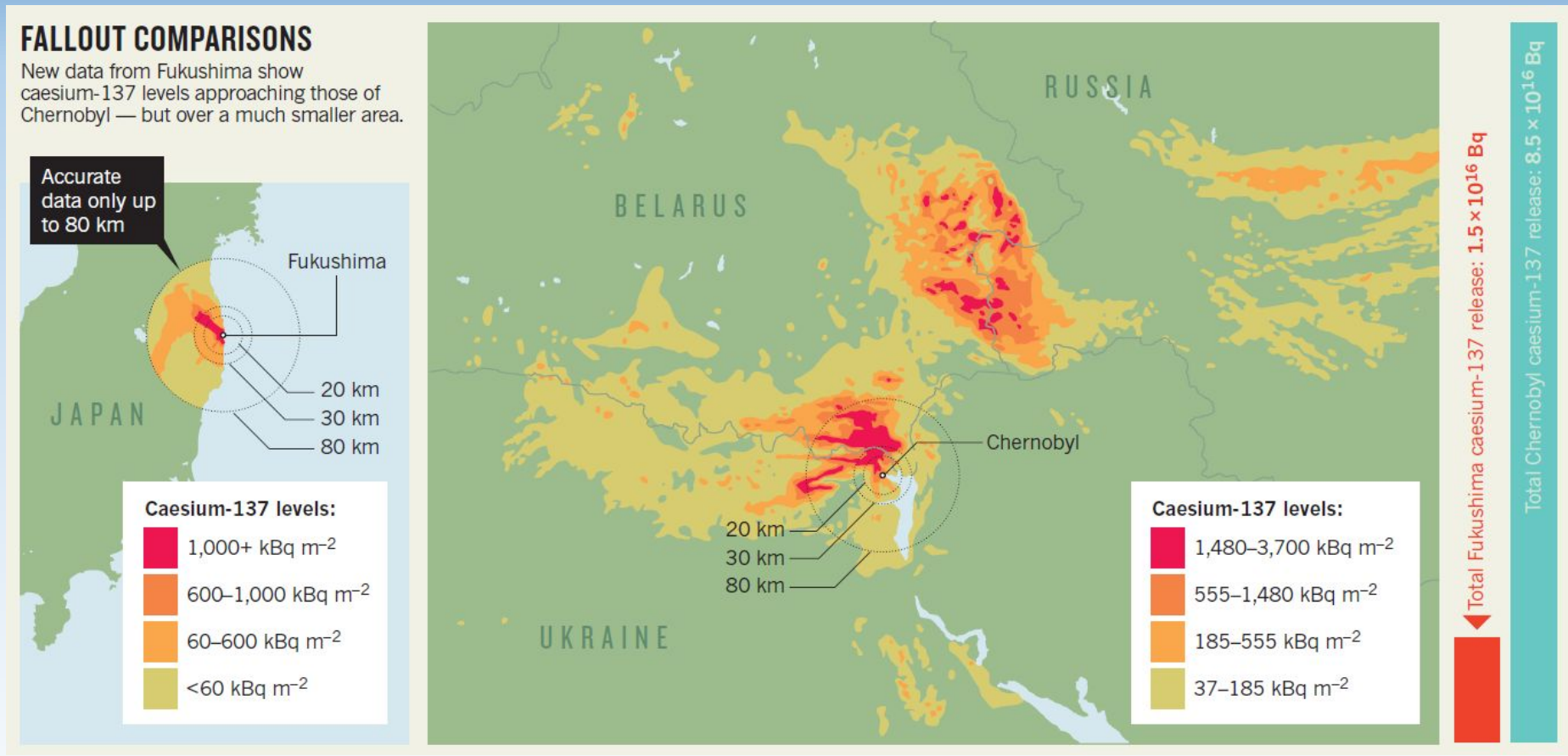
For the first five years after both accidents
(but not the emergency phase)

Comparison Fukushima – Chernobyl (same scale)



Fukushima compared to Chernobyl:
comparable Cs-deposition levels, but over smaller area

After Vandenhove et al., 2012

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Deposition and areas affected

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

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

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Affected landscapes – focus of remediation

Chernobyl

Collective and private farming, agriculture, forests, uplands

Importance of mushrooms and berries

Fukushima Daiichi

Decision to remediate evacuated areas

Importance of rice production in paddy fields

Forested catchments with steep slopes

Comparison of the contaminated areas

Factor	Chernobyl	Fukushima Daiichi
Timing	At start of growing season	Before growing season
Population density	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

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Comparison of internal exposure pathways

Factor	Chernobyl	Fukushima Daiichi
Fraction of soils with high organic matter	Moderate to High	Low
Use of K fertiliser	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

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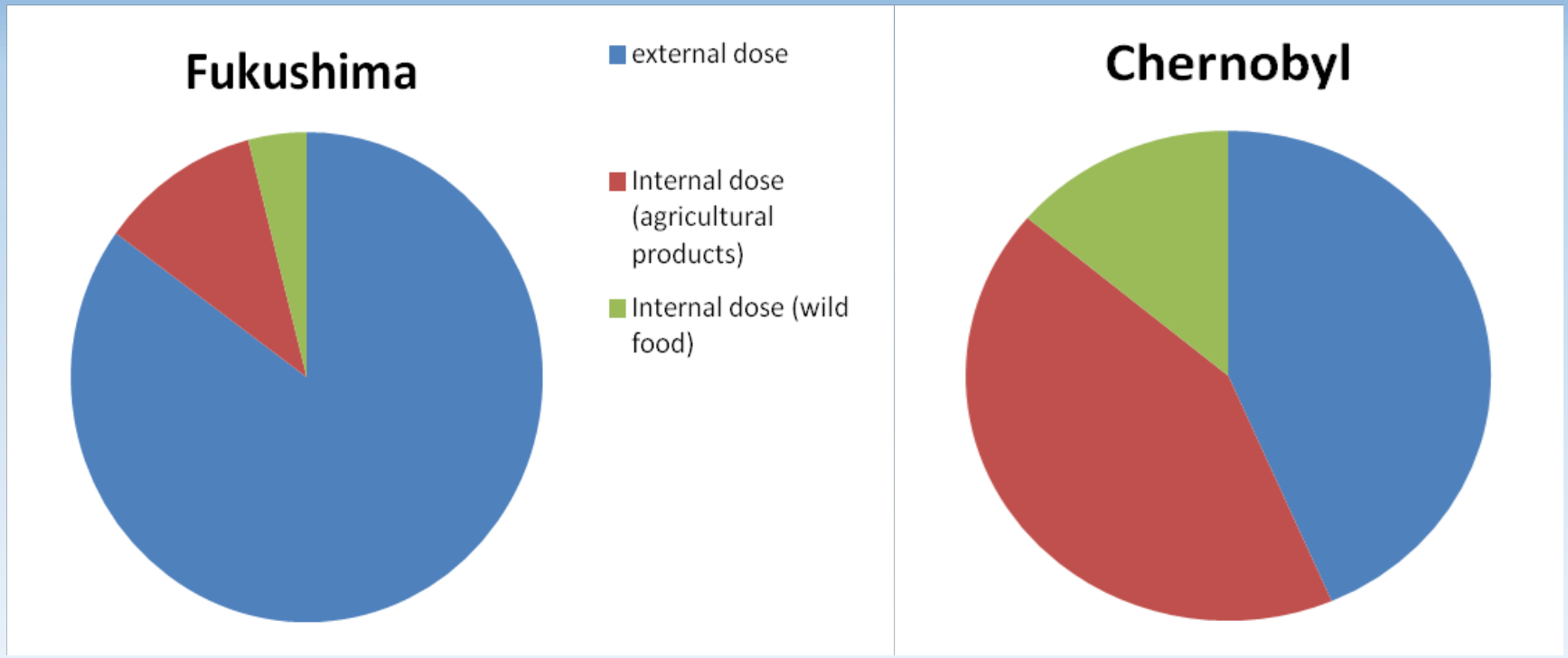
Importance of pathways



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

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

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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 100 000 people were living in areas with **> 1 mSv/y**
  - Need to **remediate to reduce their effective dose rate**
  - Return of people to evacuated areas
    - Difficult due to Sr-90 and Pu-contamination in parts of the Chernobyl exclusion zone
    - Low priority for return of people

Fukushima Daiichi

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

Interaction of long-term doses from Cs-134/Cs-137 with agricultural practice and living habits

Factor	Fukushima	Chernobyl
Intensity of agriculture	high	low
Use of potassium fertilizer	moderate to high	low
Fraction of organic acid soils low in nutrients	low	high
= > Availability of cesium in soil	**low to moderate**	**high to very high**
Intake of local food	low	**high to very high**
=> Contribution of ingestion dose to total dose	**low**	**high**

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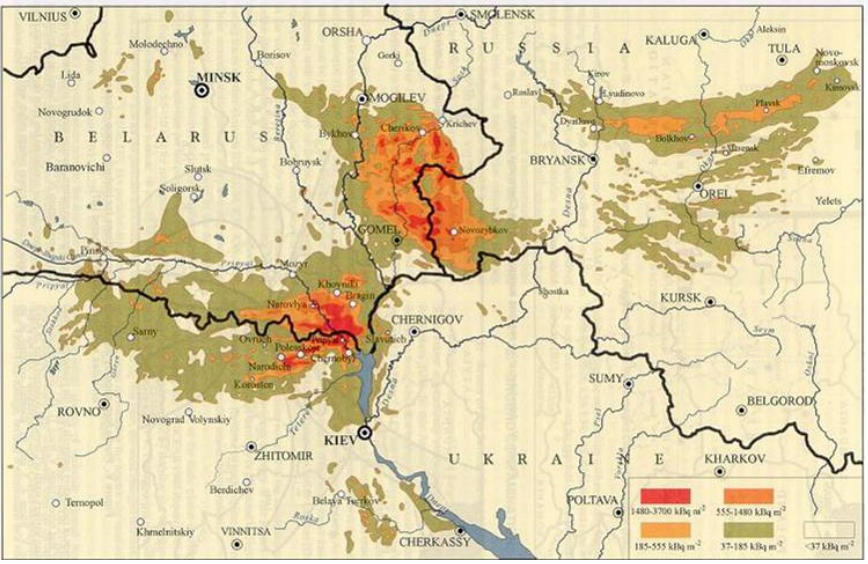
Comparison of radiological criteria

Dose cannot be easily measured, so "operational easily measurable quantities" are derive - ambient gamma dose rates (μSv/h)- deposited activity per unit area (Bq/m^2)

Factor	Chernobyl	Fukushima Daiichi
	Similarities	
	Long term goal of effective dose 1 mSv/y	
	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)

Classification of contamination in Chernobyl



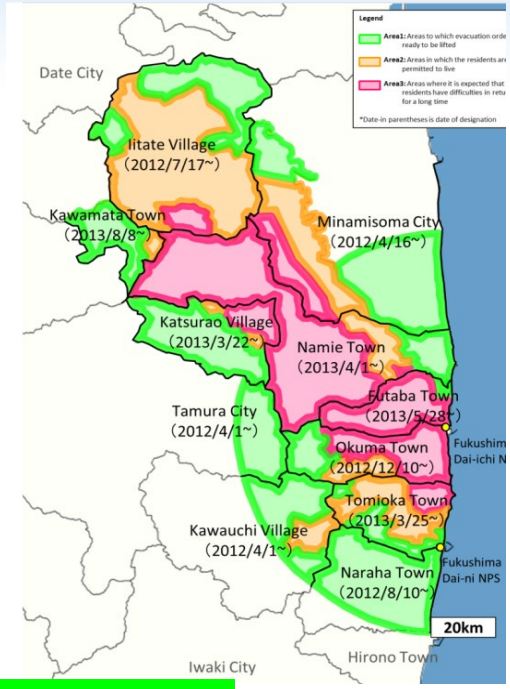
Cs-137 (kBq/m²)	Designation
Below 37	Not contaminated
37 - 185	Remediation for areas with “sensitive soils” (eg. wet peat, acid sandy)
185 - 555	Remediation applied for sandy soils and light loam soils
555 - 1480	Full scale remediation
>1480	No economic activity

- Set definition of contaminated land at 37kBq/m²
- Identified settlements where annual dose rate was > 1 mSv

Izrael 1990

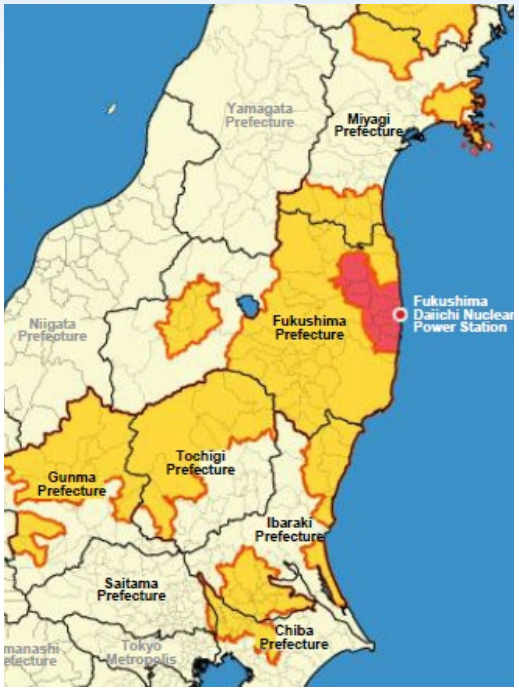
Fukushima designation of remediation areas

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)
- DA 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 dose > 1 mSv/y	ICSA and evacuated areas - SDA 1,2,3
Approach	• Focus on measures with a high effectiveness in dose reduction • Cost-benefit analysis	• Rapid implementation • Priorities – Social and cultural factors – Dose reduction even in less affected areas • Sufficient financial resources available
Cost	High	Very high
Forest	Providing advice on behaviour	Decontamination on the border of forests

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	✓	✓

Effectiveness of remediation: 2-4 fold reduction in external ambient dose rate

Important countermeasures

Chernobyl

- Use of uncontaminated feedstuff before slaughter
- Radical improvement:
  Deep ploughing, re-sowing, lime, K-fertilizer

Use of “Prussian Blue” to reduce Cs-resorption in the gut

Live - monitoring

Fukushima Daiichi

- Removal of plants, topsoil
  - Soil hardener
- Draining suspended soil from paddies
- Deep ploughing
- Use of extra K-fertilizer

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

Comparison of agriculture remediation measures

Remediation measure	Chernobyl	Fukushima Daiichi
Animal products		
Clean feeding	✓	✓
AFCF to animals	✓	
Live monitoring of domestic animals	✓	
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		✓

Forest remediation

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

Chernobyl

Providing information and advice

- Spatial variation of contamination
- Which mushrooms 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

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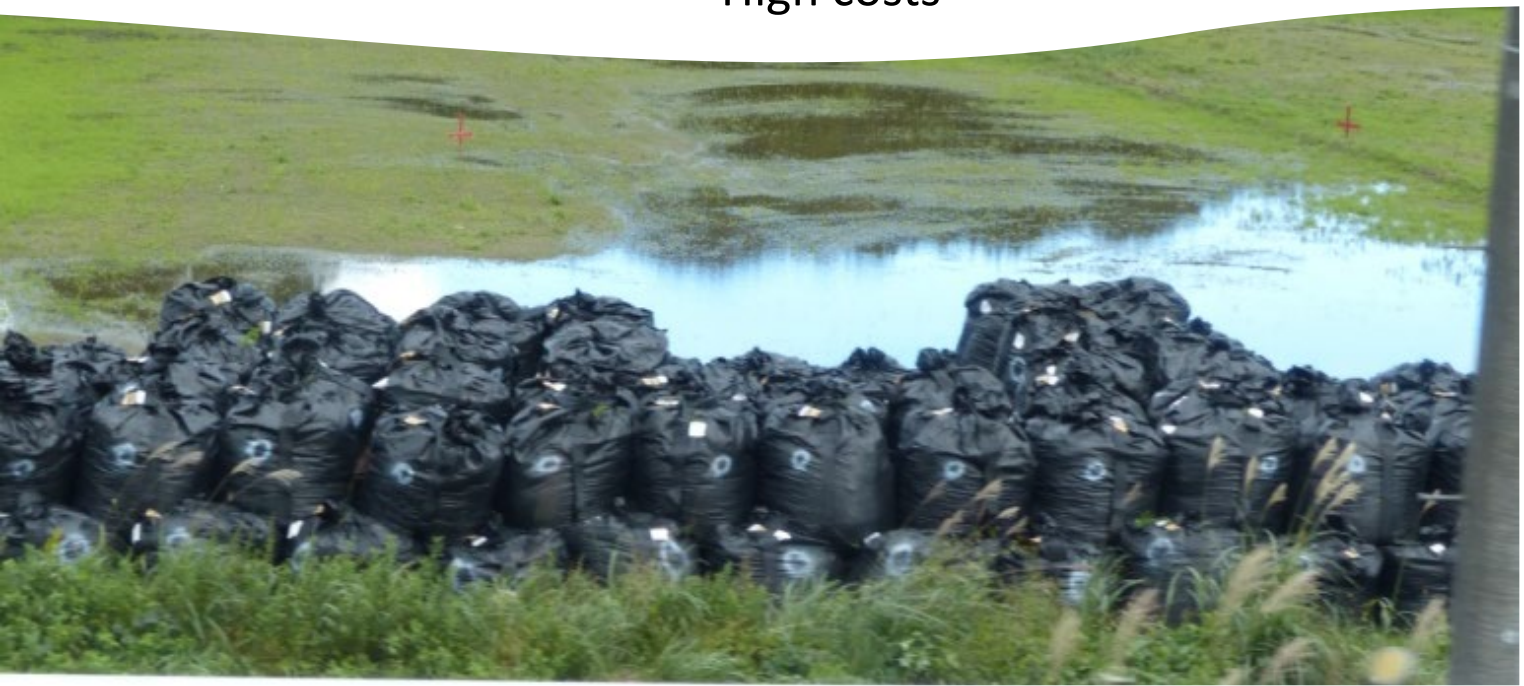
Waste generation and management

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



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SUMMARY

- **Radiological consequences**
  - Consequences of the FDNPP accident are much lower than of Chernobyl
  - The **scale of remediation** activities is **comparable**
- **Remediation**
  - For both accidents, the **long term goal** of remediation is an individual additional annual effective dose of 1 mSv/a
  - **Radiological criteria** for remediation in Japan **are lower** than those in the USSR
  - In Japan, **reduction of limits for food** and other remediation action levels
  - Therefore, relatively **higher costs** in Japan
  - Decision to **remediate evacuated land in Japan**
- **Chernobyl**
  - The consideration of **dose saved** and the **related cost** was an important part of the remediation strategy.
- **Fukushima**
  - For remediation of affected areas **radiological and social and cultural** considerations had **high priority**

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