Agricultural land management options following large-scale environmental contamination

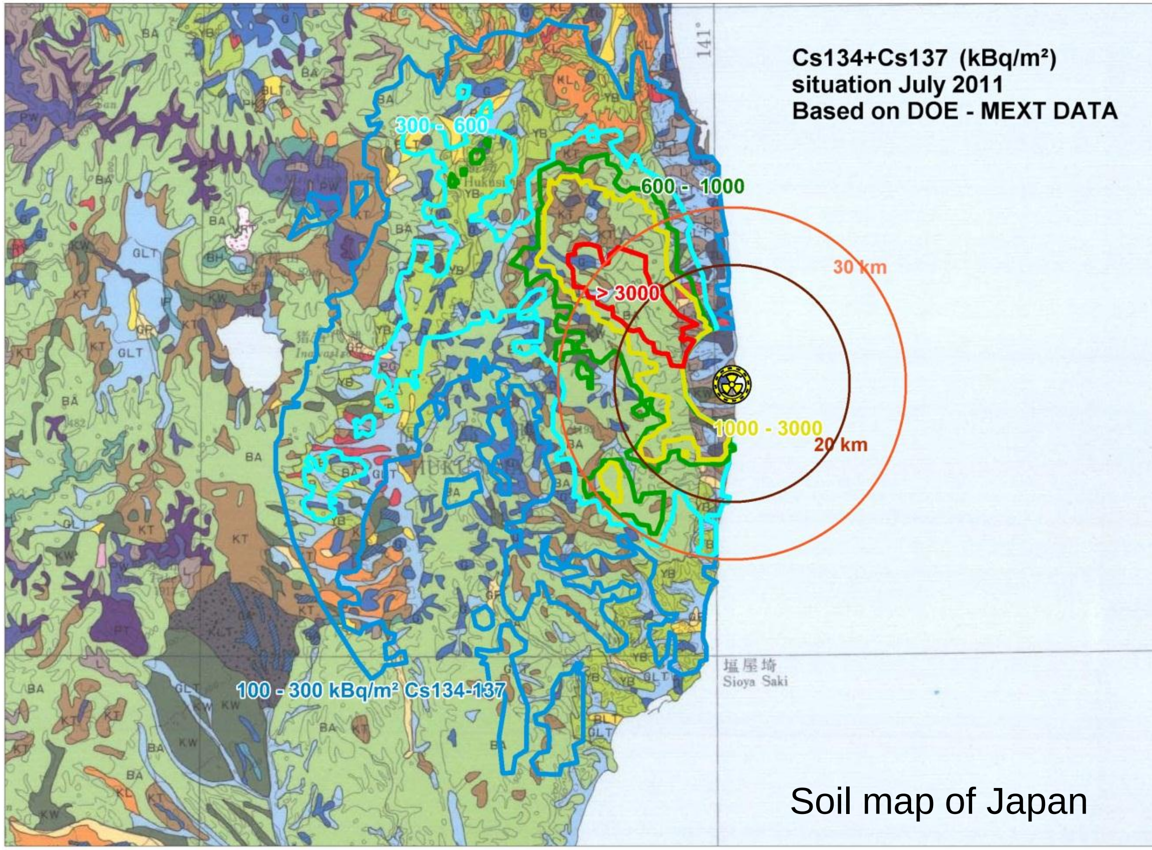
Evaluation for Fukushima affected territories

Hildegarde Vandenhove
Biosphere Impact Studies – SCK•CEN
hvandenh@sckcen.be

IEM - Radiation Protection after the Fukushima Daichi Accident
17-21 February 2014, IAEA, Vienna

Complex contamination situation

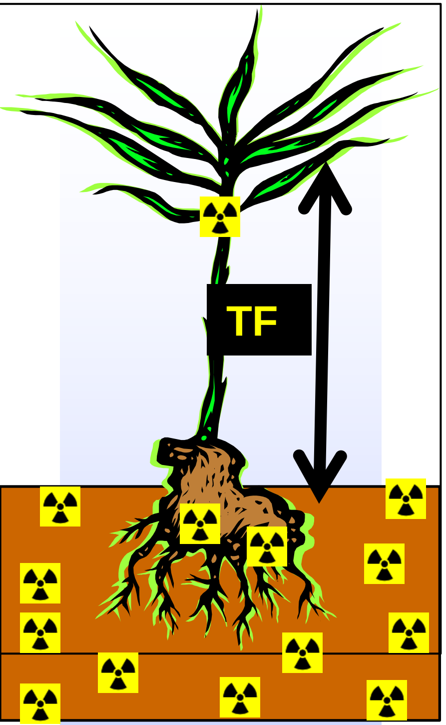
- Japan → 70 % forests
- Patchy soil pattern
  - More than 1000-fold difference in caesium uptake by crops as function of soil type
- For a same soil, plants show large difference in uptake of caesium
  - E.g. lettuce high uptake rice low uptake
- "A-typical" soils
  - 16% of soils are andosols



Soil map of Japan

SOME SOILS SO HIGH TRANSFER THAT EVEN WITH LOW SOIL CONTAMINATION FOOD OR FODDER LEVELS EXCEEDED

Long term risk in agricultural ecosystems



- In case of Fukushima: Mainly related to radiocaesium (^{137}Cs + ^{134}Cs)
- Caesium resembles K and is therefore readily taken up by crops : $^{137}Cs^{+} \leftrightarrow K^{+}$

$$Transfer\ factor\ (TF) = \frac{Concentration\ in\ crop\ (\frac{Bq}{kg})}{Concentration\ in\ soil\ (\frac{Bq}{kg})}$$

Countermeasures aim at limiting transfer to food chain

Mechanical soil treatment

TRANSFER FACTOR ⇩

REMOVE ACTIVITY

TRANSFER FACTOR ⇩

DILUTE ACTIVITY

- Top soil removal
  - High effectiveness (75 - ~100 % removal)
  - Japan – required if > 5000 Bq/kg
  - Disadvantages
    - WASTE! 400 m^3/ha (4 cm removal)
    - Potentially high exposure of remediation workers
    - Loss in soil fertility
- Ploughing
  - Factor 1-10 reduction in plant uptake, factor 2-10 reduction in dose
  - No waste produced
  - Limitations
    - Loss in soil fertility (e.g. podzols)
    - Induces erosion
    - Limited applicability: stoney soils, slopes

SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

Soil-based countermeasures

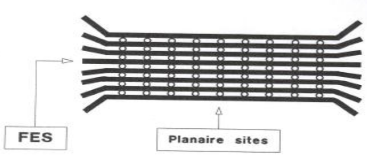
TRANSFER FACTOR

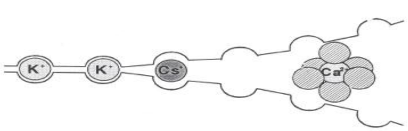
COMPETITION

- Increase competing ions
  - K <-> Cs
  - Effectiveness: 1 - ~3
  - Only for K-deficient soils

TRANSFER FACTOR

FIXATION





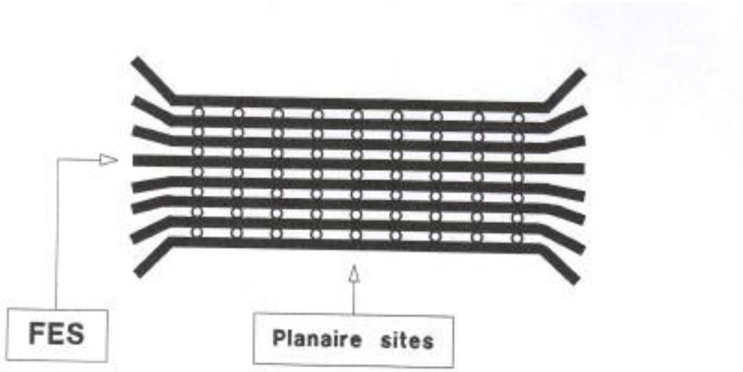
- Increased fixation
  - Soil ammendments (zeolites, sapropels, mica's, illites, bentonites, …)
  - Effectiveness: 1 - ~10

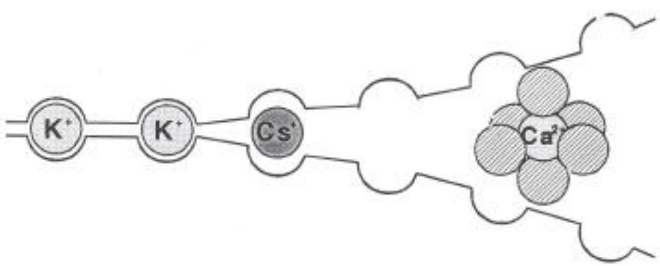
TRANSFER FACTOR

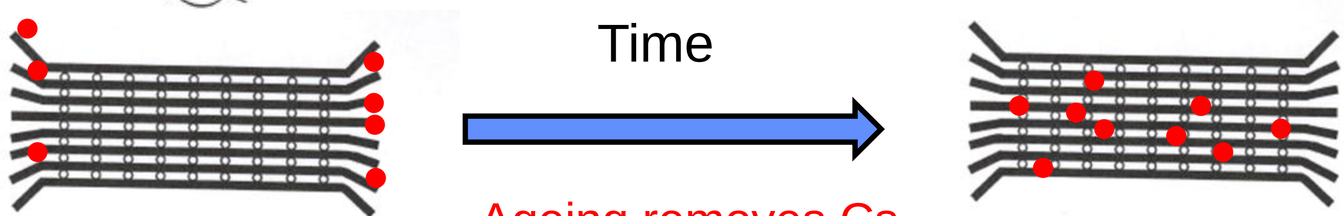
FIXATION

Soil chemistry

- High selective sorption of Cs on Frayed-Edge Sites (FES)
- Sorption-desorption of Cs on FES by ion exchange with K^+ and NH_4^+
- **Radiocaesium Interception Potential** (RIP) of soils →measure for fixation potential







Ageing removes Cs from surface to inner clay layers→ fixation

(Cremers et al. 1988, *Nature*)

SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

TRANSFER FACTOR
FIXATION

Estimating ammendment efficiency for Cs

Adsorption potential (AP) = RIP

$$Effect = \frac{AP_{soil} \times mass_{soil} + AP_{am} \times mass_{am}}{AP_{soil} \times mass_{soil}} = 1 + \frac{AP_{am} \times mass_{am}}{AP_{soil} \times mass_{soil}}$$

If 1 % ammendment, AP_{am}/AP_{soil} should be 100 for a two-fold effect!!

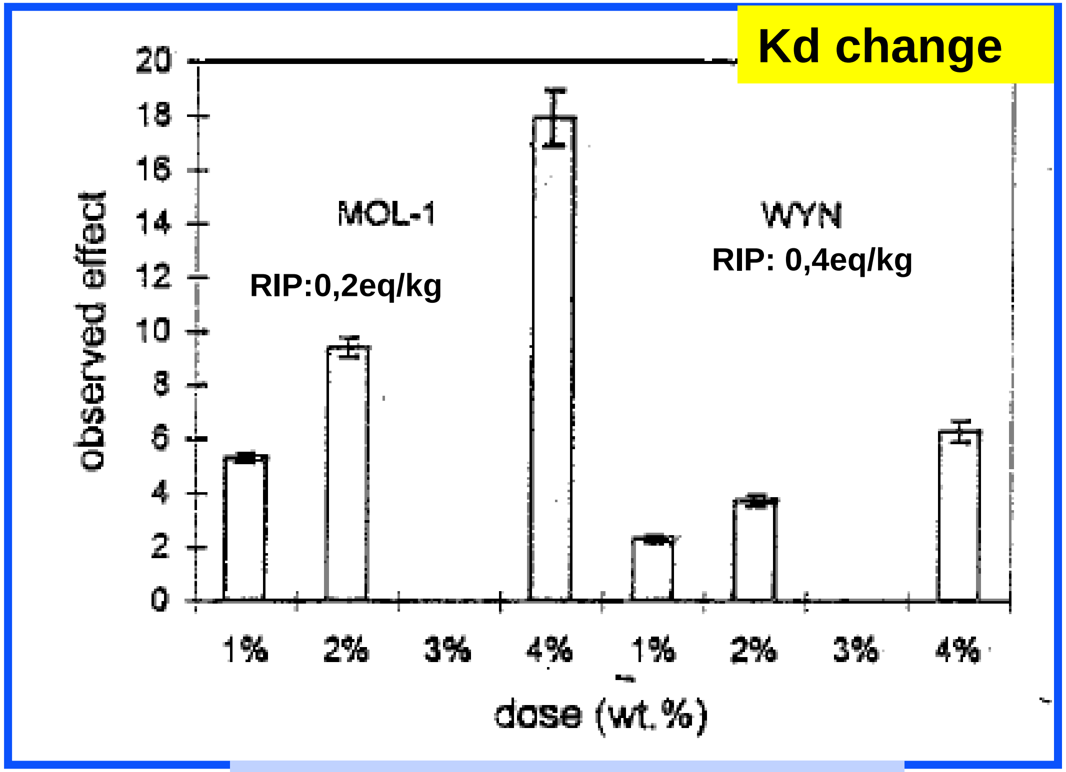
Surface contamination over 2 cm depth: 3 t/ha ammendment needed
Homogeneous cont over root depth: ~30 t/ha ammendment needed

$$Effect_{Cs} = 1 + \frac{RIP_{am} \times mass_{am}}{RIP_{soil} \times mass_{soil}}$$

STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

TRANSFER FACTOR
FIXATION

Both at soil level (Kd-change) and plant level (change in TF) observations and predictons agree



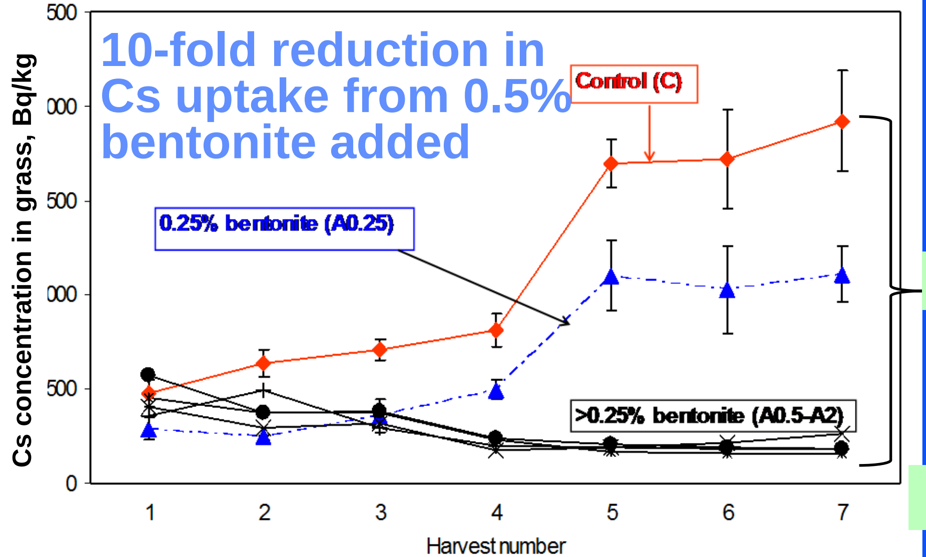
Zeolite (mordenite): RIP: 66 eq/kg

For 1 % ammendment, if AP_{am}/AP_{soil} 100→ 2-fold effect
Here: AP_{am}/AP_{soil} ~ 300: for 1% → 4-fold effect

Source, Zeolites, 1997, 18: 218-224; 225-231; Eu J Soil Sc, 2003, 54, 91-102; 2004, 55, 513-522

Bentonites converted to potassium form and subjected to drying and wetting become very efficient Cs-sorbents

STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE



~10

1%

~900

Follow-up experiment

54 different bentonites converted to K-form, 25 DW cycles

RIP increased between 1 & 160-fold
RIP_{bent} in soil /bent mix: → 99 eq/kg

→ 200-1000 more than for sandy soil
→ 1 % addition: 4-10 fold reduction in TF

RIP-values

Podzol:	0,1 eq/kg
K-bentonite:	
initial:	6 eq/kg
after plant growth:	89 eq/kg
Illite:	11 eq/kg

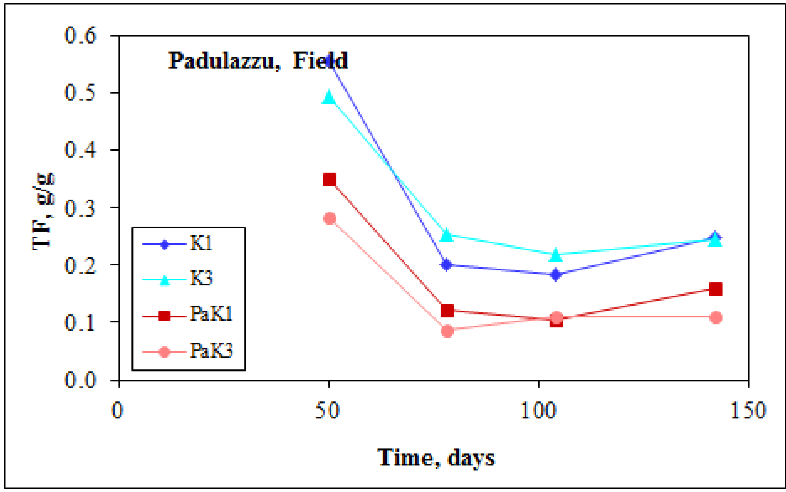
increase in radiocaesium sorption ascribed to collapse of clay sheets into illite-like structure during drying/rewetting in presence of K

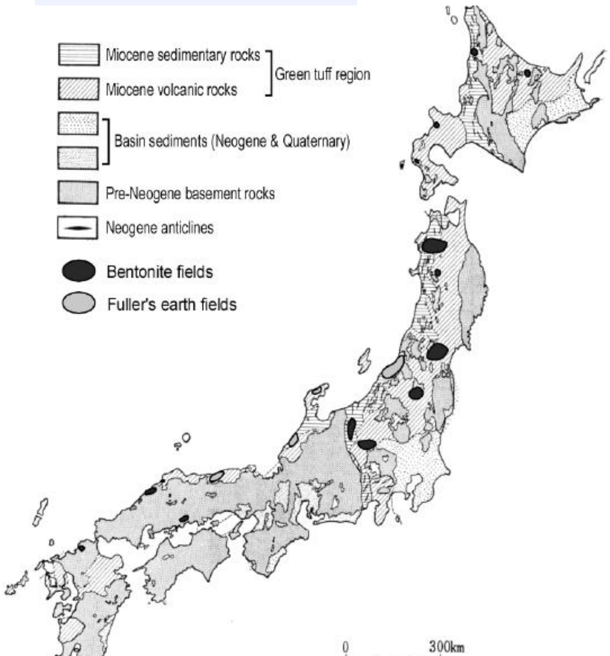
Sources: Eu J Soil Sc, 2003, 54, 91-102; 2004, 55, 513-522

TRANSFER FACTOR
FIXATION

Potential for amendments

- Many amendments: too low AP, high cost (like e.g. sapropel) and limited availability
- Only effective if $AP_{am}/AP_{soil}>100$
- Effects observed under controlled conditions but seldom in field
- Bentonite+K-carbonate in field works



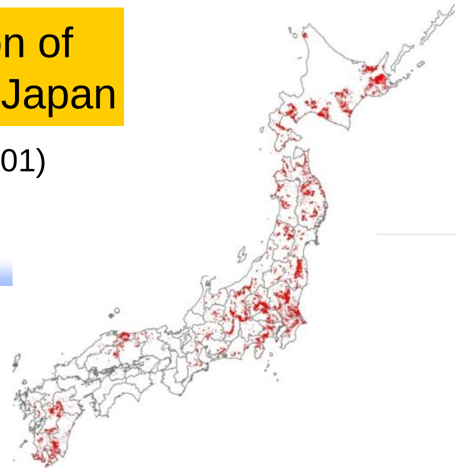


Source: Geological Survey of Japan, no. 425

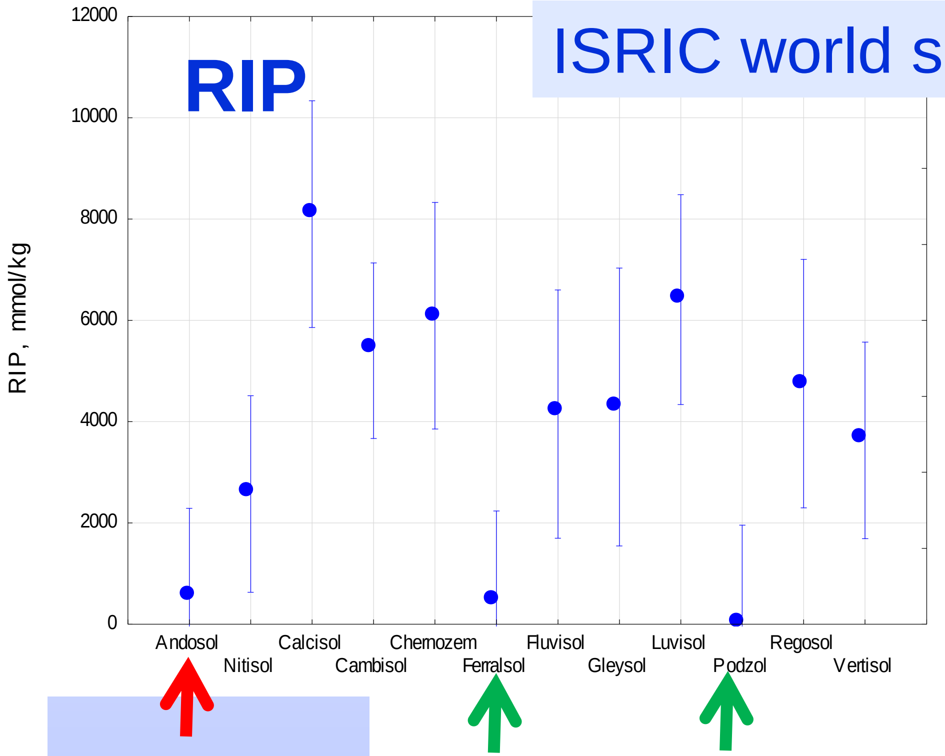
- Locally available bentonites
  - Test effectiveness – $AP_{am}/AP_{soil}>100$
  - Mixing in at 1-2% in upper soil layer and allowing natural drying rewetting
  - For paddy soils: allow paddy soil to dry out for a while ???

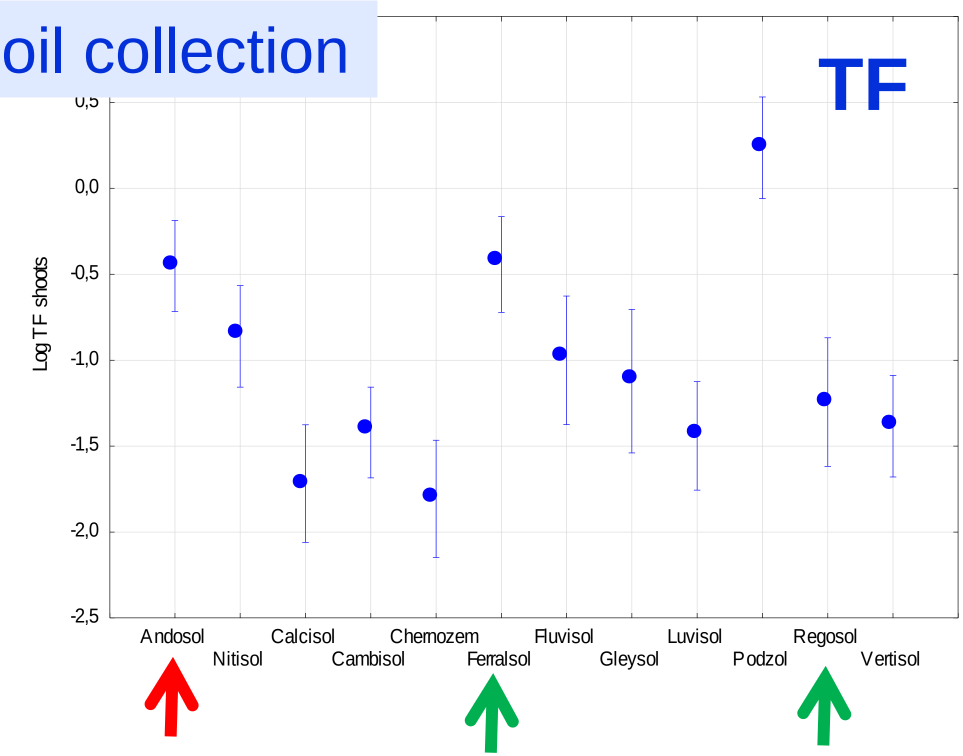
Distribution of Andosols in Japan

(NIAES, 2001)



ISRIC world soil collection



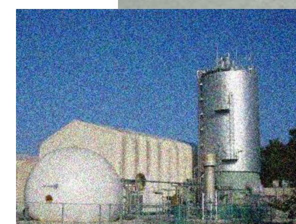


Andosols generally low RIP
Significant relation RIP and TF

SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

Alternative land use in areas where food production is jeopardized

- Biofuel crops
  - Biogas through fermentation of contaminated biomass
  - Combustion/gasification
    - Contaminated wood, willow, miscanthus, ..
  - Liquid biofuels
    - Biodiesel from rapeseed, bioethanol from sugar beet…

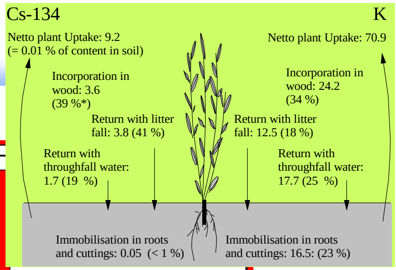


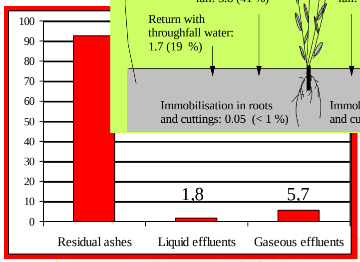
- Fibre crops
  - For rope, paper, isolation material,
  - Hemp, flax, Ramie…

Put contaminated land to (some) value

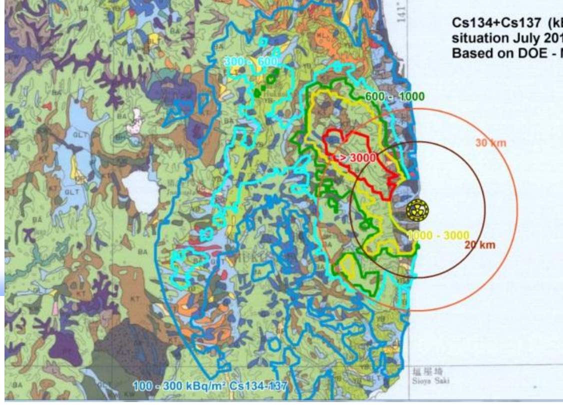
For evaluating feasibility of alternative landuse: Holistic approach required

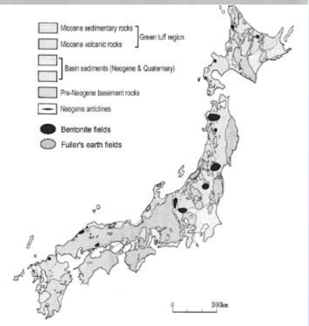
- Radioecology
  - Uptake and fate during production and conversion (waste, end product)
  - Some info for biofuel crops, none for fibre crops
- Dosimetry
  - Dose during crop production, conversion, transport and waste management
- Agricultural feasibility
  - Crop requirements, crop cultivation requirements
- Conversion facilities
- Economics
  - Production, conversion, waste disposal
- Public acceptance
  - e.g. familiarity with culture, loss of confidence in end products

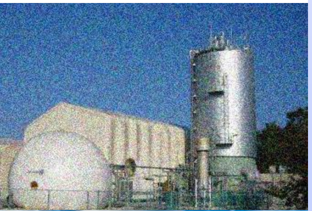




Conclusions







- Careful mapping of contamination and soil characteristics would allow identifying areas most vulnerable to high soil-to-plant transfer and areas where treatment with agrochemicals or ploughing would be feasible & effective
- Effectiveness of countermeasures (CM) to be checked for Japanese conditions
  - Bentonites option?
- Some areas may remain too contaminated and too vulnerable for transfer to allow for food production
  - Alternative land-use required→energy/fibre crops?
- But, will public buy food/products from contaminated area?

SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

- Thanks for your attention
- Questions?