The ECOSYS/FDMT model
Overview, advantages, limitations and suggestions for further development

Gerhard Proehl

CONFIDENCE Workshop:

Do Process-Based Models have a role in human food chain assessments

CIEMAT, Madrid (Spain)

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ECOSYS-87: A DYNAMIC MODEL FOR ASSESSING RADIOLOGICAL CONSEQUENCES OF NUCLEAR ACCIDENTS

H. Müller and G. Pröhl*

Abstract—**The time-dependent radioecological simulation model ECOSYS-87 has been developed to assess the radiological consequences of short-term depositions of radionuclides. Internal exposure via inhalation and ingestion, as well as external exposure from the passing cloud and from radioactivity deposited on the ground, are included in the model. The site-specific parameter values of the model are representative of Southern German agricultural conditions; however, the model design facilitates adaption to other situations. The ingestion dose is calculated as a function of time considering 18 plant species, 11 animal food products, and 18 processed products. The ingestion and inhalation exposure is estimated for six age groups using age-dependent consumption and inhalation rates and age-dependent dose factors. Results demonstrate a pronounced influence regarding the time of year (season) of deposition on the ingestion dose and on the relative importance of the exposure pathways. Model results compare well with activities in foods measured after the Chernobyl accident.**
Health Phys. 64(3):232–252; 1993

Key words: accidents, nuclear; exposure, radiation; food chain; transport, environmental

3) External exposure from radionuclides in the passing cloud; and
4) External exposure from radionuclides deposited on the ground.

Models for the dose assessment, after accidental releases, have to consider the time dependency of the transfer processes since equilibrium in the model compartments will not be reached for a long time. Therefore, dynamic modeling of the processes and consideration of the seasonality in the growing cycles of crops, in the feeding practices of domestic animals, and in human dietary habits are essential. Furthermore, the models have to be flexible enough to enable the simulation of the actual region-specific radioecological situation in case of an emergency.

In the late 1970s, the development of dynamic radioecological models was started and led to a number of such models (e.g., Booth et al. 1971; Pleasant et al. 1980; Linsley et al. 1982; Matthies et al. 1982; Koch and Tadmor 1986; Whicker and Kirchner 1987). Some of these models were used to estimate the radiological consequences of the Chernobyl accident soon after its event (e.g., ISS 1986). After this accident, many meas-

1993

2006

Model Description of the Terrestrial Food Chain and Dose Module FDMT in RODOS PV6.0

RODOS REPORT

DECISION SUPPORT FOR NUCLEAR EMERGENCIES

RODOS(RA3)-TN(03)06

1997

ADAPTATION OF ECOSYS-87 TO HONG KONG ENVIRONMENTAL CONDITIONS

C. B. Poon,* S. M. Au,* G. Pröhl,[†] and H. Müller[†]

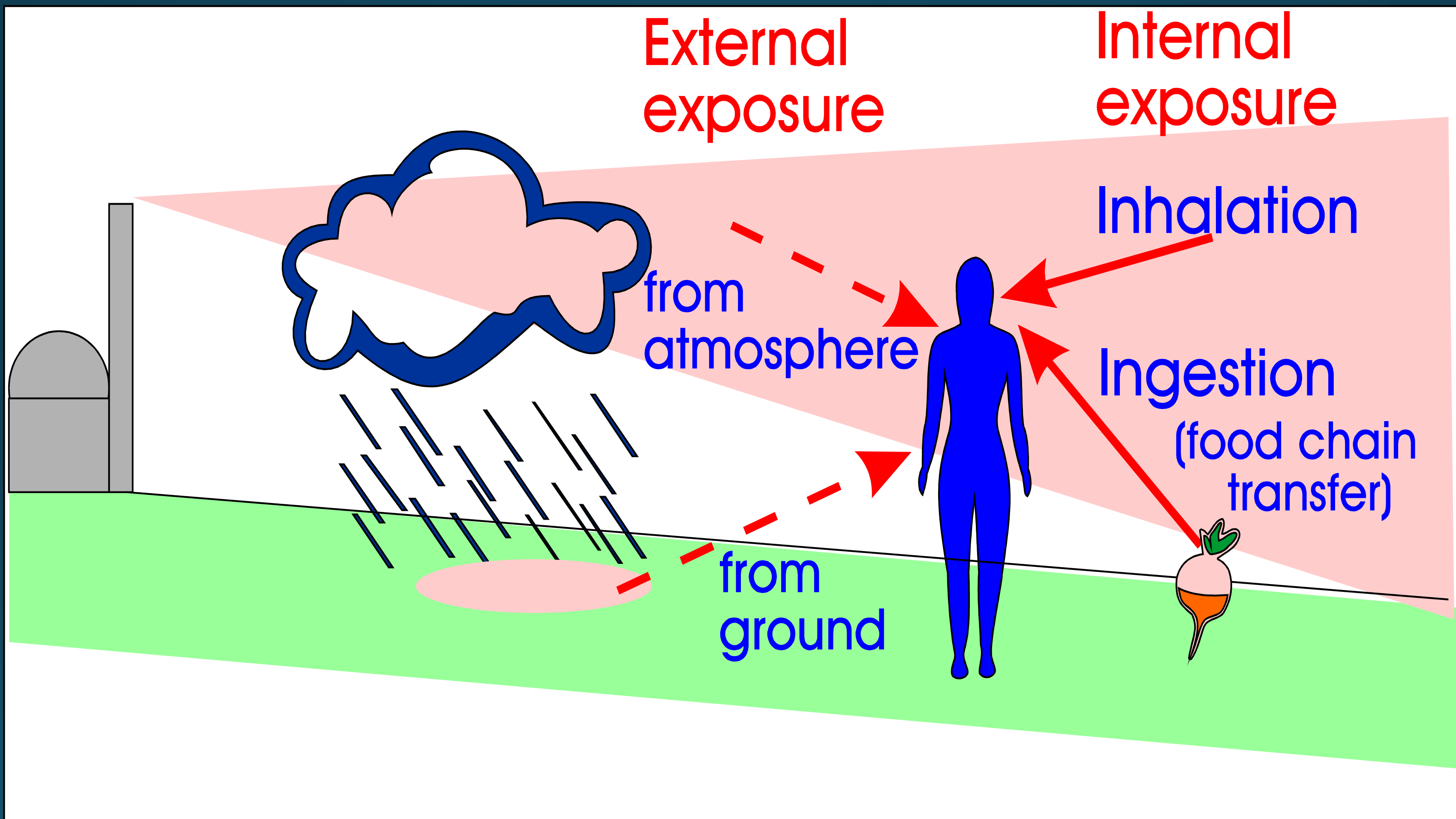
Abstract—**This paper describes the adaptation work carried out on the radioecological model ECOSYS for radionuclide transfer in the Hong Kong ecological environment. The adapted model predicts that the ingestion dose due to dry deposition in Hong Kong shows less pronounced seasonal dependence than that in Germany. This is mainly attributed to differences in climate, agricultural and farming practices adopted in the two places. Brief discussions on model sensitivity, uncertainty, and validation are also given.**
Health Phys. 72(6):856–864; 1997

Key words: accidents, nuclear; environmental impact; food chain; ingestion

Europe. Many foodstuffs important in Germany could be neglected for the situation in Hong Kong. Other foodstuffs not considered before in the model had to be introduced. Moreover, the growth characteristics of plants had to be modified for the situation in Hong Kong; and

- ECOSYS-87 estimated the ingestion dose assuming that all foodstuffs consumed were produced locally. This assumption was fairly acceptable in central Europe, but it was inappropriate for Hong Kong since Hong Kong imported quite a lot of food from distant sources and overseas countries.

The problem



External exposure
Internal exposure
Inhalation
from atmosphere
Ingestion
(food chain transfer)
from ground

Motivation for development

Questions raised during and after the Chernobyl accident

- Time-dependent activity levels
  - Crops
  - Animal products
  - Processes products: flour, milk, beer, …..
- Influence of the season
- Influence of feeding regimes
- Simulation of countermeasures
- Long-term activities in food and feed products
- Importance and time-dependence of external exposure

- etc…..

=>Model to provide assistance in accident management and decision making

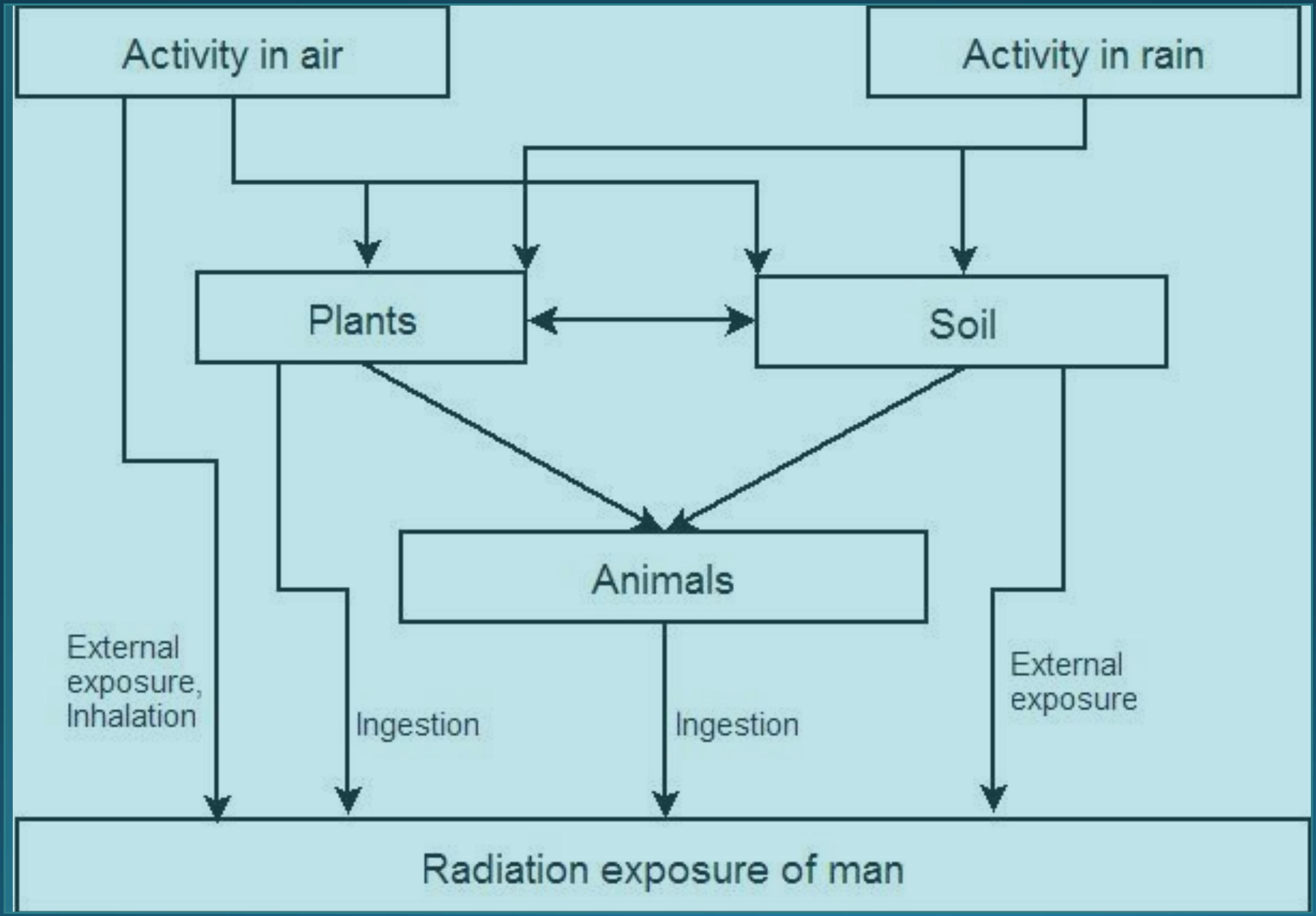
Requirements identified after the Chernobyl accident

- Endpoints needed
  - Time-dependence of activities
  - Doses to peoples
  - Importance of pathways
- Flexibility to address a wide range of exposure conditions
  - Regionality
    - Growing periods of crops
    - Include all relevant regional foods
    - Agricultural practise
  - Seasonality
    - Plant growth
    - Feeding habits
    - Intake habits
- Possibility to simulate countermeasures
- Provide answers to “What –if questions”

Requirements for modelling

- Input
  - Quantities measured during environmental monitoring
    - Activity in air
    - Rainfall
  - Differentiate between dry and wet deposition
- Include a wide range of crops and animal products
  - Address specific situations
  - Enable response to “individual” questions
- Simple models
  - Use of readily available parameters
  - Use of parameters that are easy to determine

ECOSYS model



Plant and animal products considered

Primary products	Foodstuffs	Feedstuffs
Grass (intensive)	Spring wheat, whole grain 2	
Hay (intensive)	Spring wheat flour	Grass, intensive
Grass (extensive)	Spring wheat, bran	Hay, intensive
Hay(extensive)	Winter wheat, whole grain	Grass, extensive
Maize	Winter wheat, Flour	Hay, extensive
Corn cobs	Winter wheat, Bran	Maize
Potatoes	Rye, whole grain	Corn cobs
Beet	Rye, Flour	Potatoes
Beet leaves	Rye, Bran	Beet
Winter barley	Oats	Beet leaves
Spring barley	Potatoes	Winter barley
Winter wheat	Leafy vegetables	Spring barley
Spring wheat	Root vegetables	Winter wheat
Rye	Fruit vegetables	Spring wheat
Oats	Fruit	Rye
Leafy vegetables	Berries	Oats
Root vegetables	Milk	Distillery residues
Fruit vegetables	Condensed milk	Brewing residues
Fruit	Cream	Skim milk
Berries	Butter	Milk substitute
Cows' milk	Cheese (rennet coagulation)	Whey (rennet coagulation)
Sheep milk	Cheese (acid coagulation)	Whey (acid coagulation)
Goats' milk	Goats' milk	
Beef (lactating cattle)	Sheep milk	
Beef (non-lactating cattle)	Beef (lactating cattle)	
Veal	Beef (non-lactating cattle)	
Pork	Veal	
Lamb	Pork	
Roes deer	Lamb	
Chicken	Chicken	
Eggs	Roe deer	
	Eggs	
	Beer	

Contamination routes for plant products

Short-term

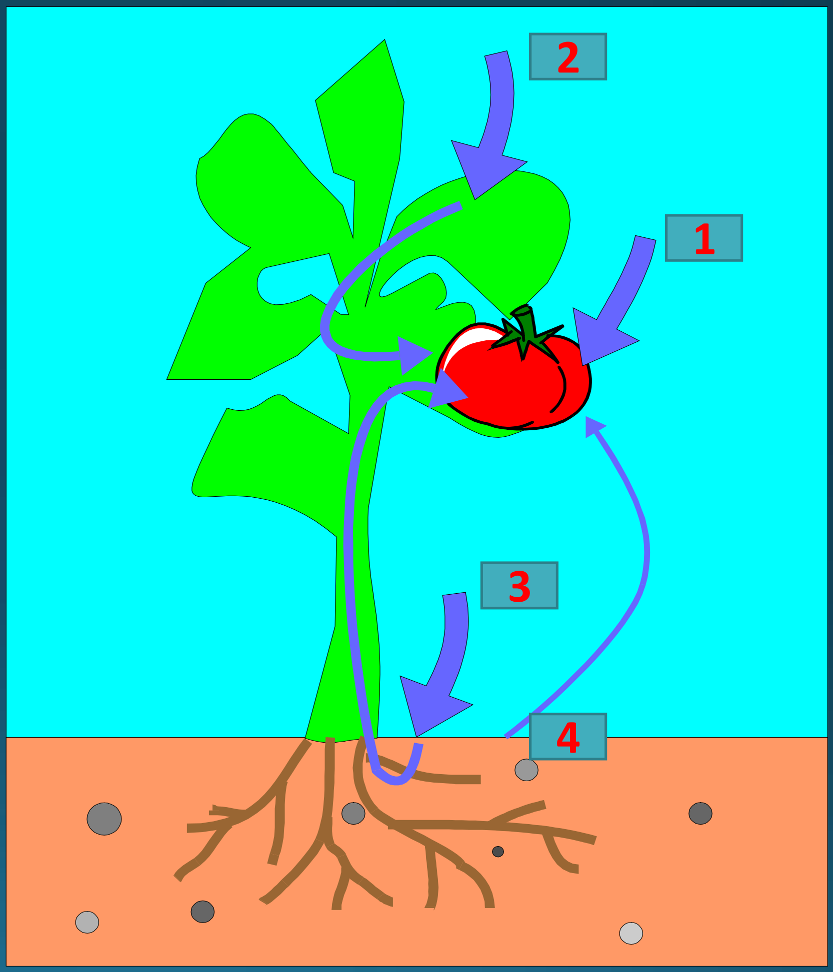
1 Direct deposition onto edible parts of plants

2 Deposition onto leaves
-> transport to the edible parts

Long-term

3 Deposition on soil and uptake through the roots

4 Resuspension of dust and re-deposition on leaves and fruits



Simple modelling for dose assessment

Pathway	Starting point	Process	Parameters
Ingestion	Activity in air, Wet deposition	Activity intake and metabolism in the body	Dose coefficients (age, RN)
Inhalation	Activity in air	Activity intake and metabolism in the body	Dose coefficients (age, RN)
External - cloud	Activity in air	Irradiation from activity in air	Dose coefficients (age, RN) Shielding Occupancy
External - ground	Total deposition	Irradiation from activity on the ground	Dose coefficients (age, RN) Shielding Occupancy
Exposure of skin	Deposition on skin		Dose coefficients (age, RN) Percentage of skin covered

Simple modelling in food chains

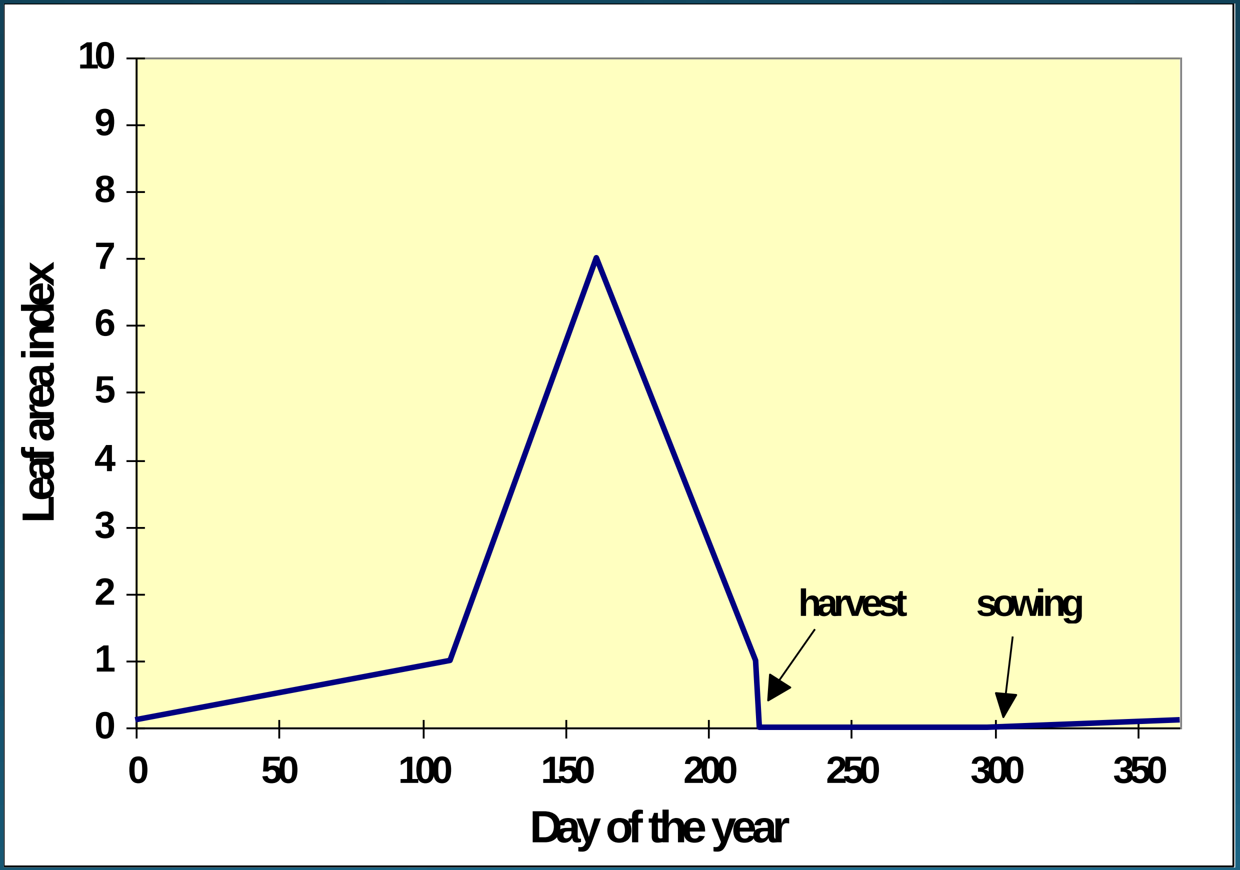
Process	Starting point	Process	Parameters
Deposition	Activity in air	Dry deposition	Deposition velocity (LAI)
	Activity in rain, rainfall	Interception	Interception factor (LAI, rainfall, element)
Foliar uptake	Activity deposited on plant	Systemic transport	Translocation factor (crop, time deposition -> harvest, element)
Uptake from soil	Activity in soil	Uptake by roots	TF soil-plant
		Resuspension	Soil mass per unit plant mass
		Migration to deep soil	Half-lives in soil (layer thickness, element)
Transfer to animals	Activity in feed stuffs	Activity intake and metabolism	Transfer factor
			Biological half-lives
Processing of crops and products		Accumulation and depletion	Processing factors

Seasonality

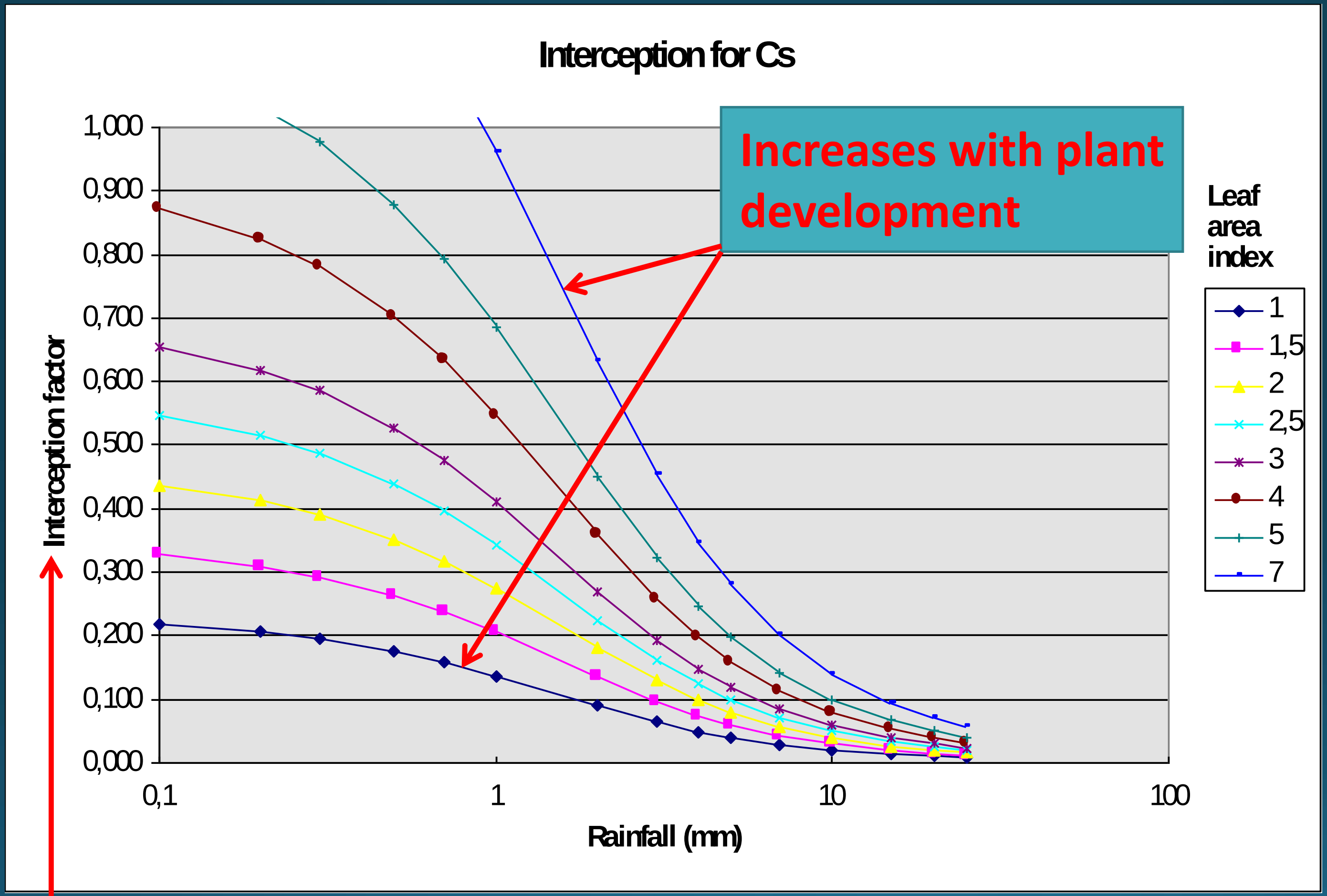
Especially relevant in the year of deposition

- Stage of development of crops
  - Leaf area index
  - Standing biomass
- Feeding regimes
- Intake rates
  - Less leafy vegetables in winter, more in the rest of the year

Development of leaf area index of winter wheat

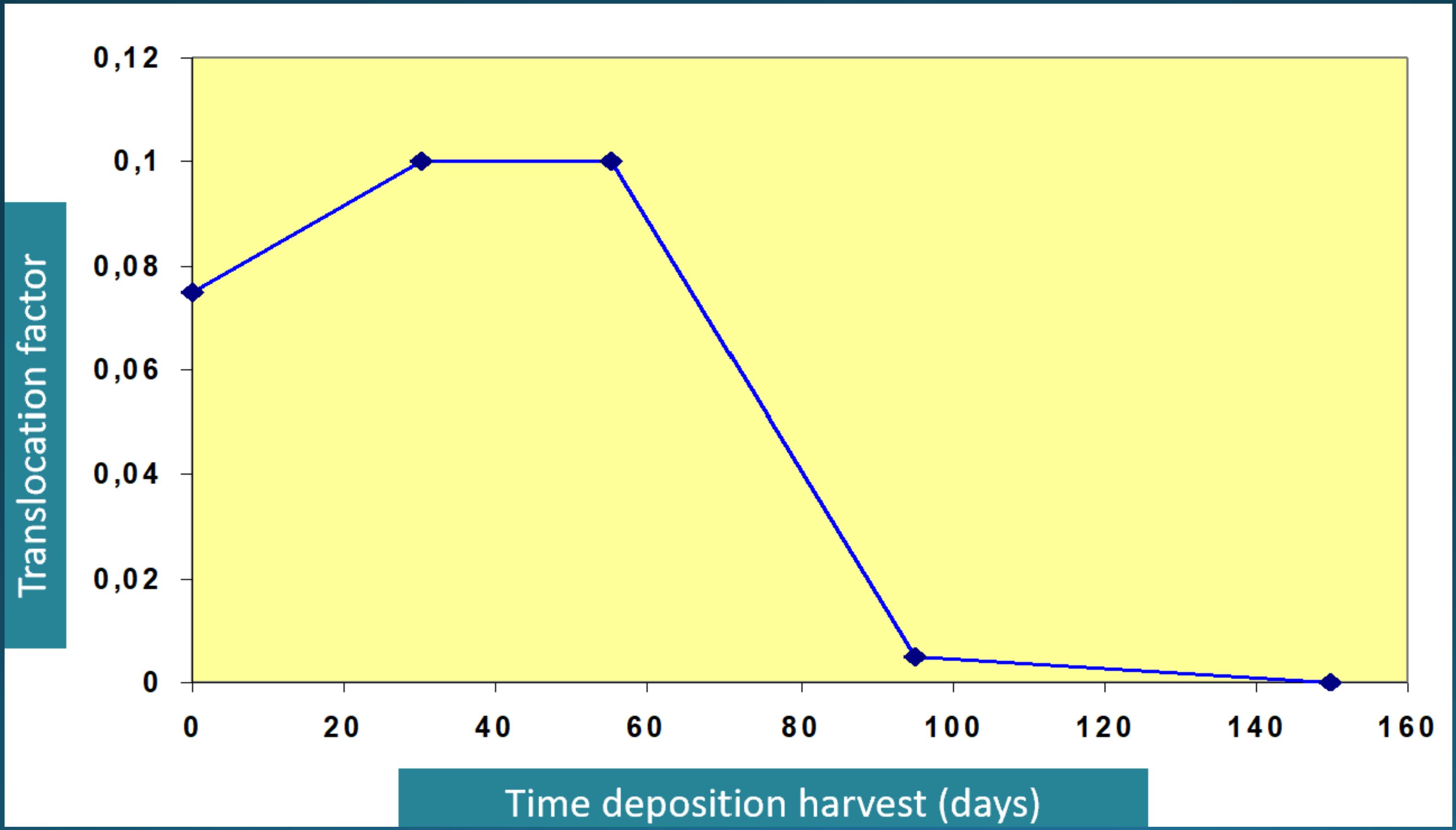


Interception of wet deposited radionuclides on plants



Decreases with increasing rainfall

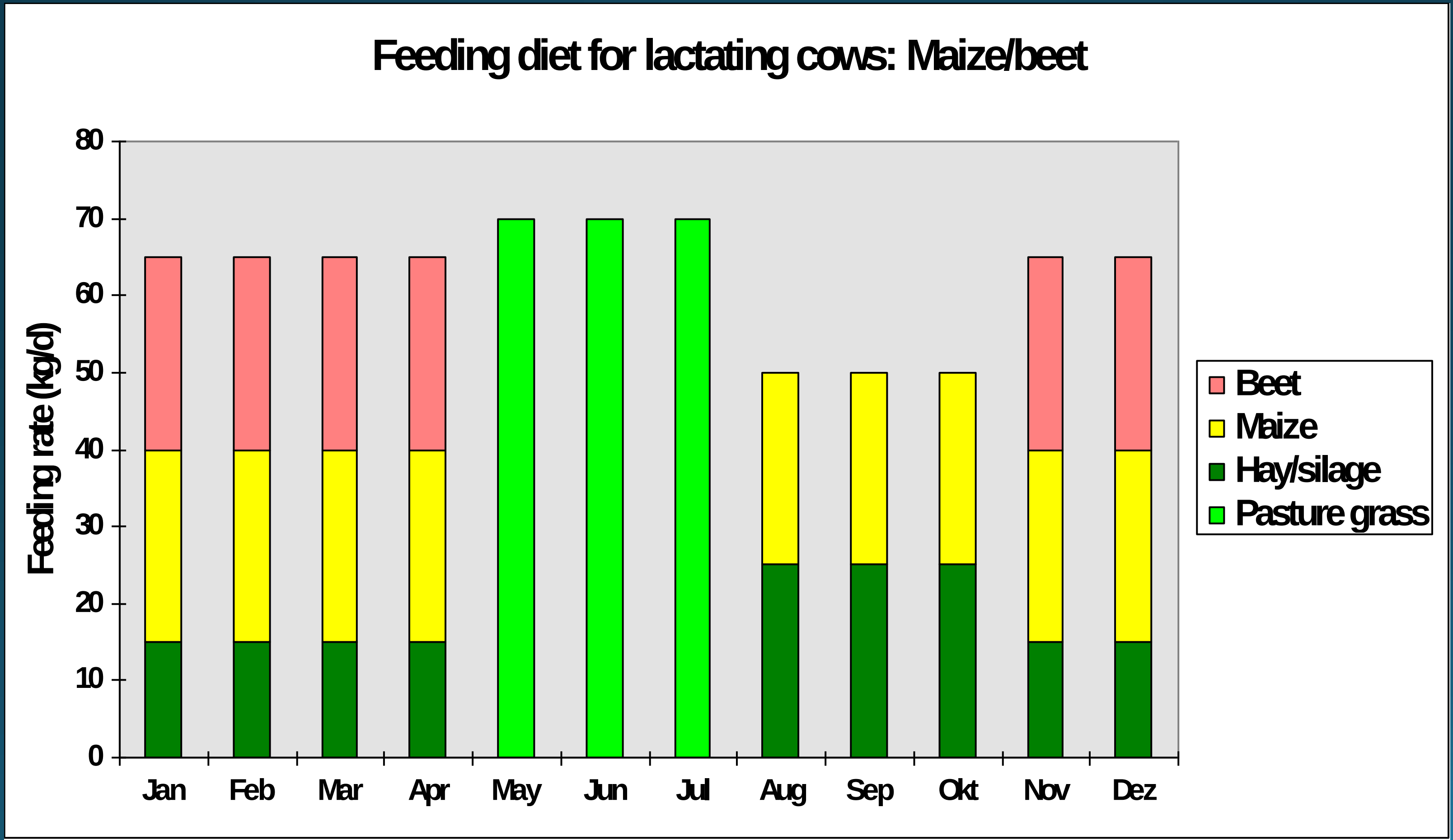
Translocation factor as function of time between deposition and harvest for Cs in winter wheat



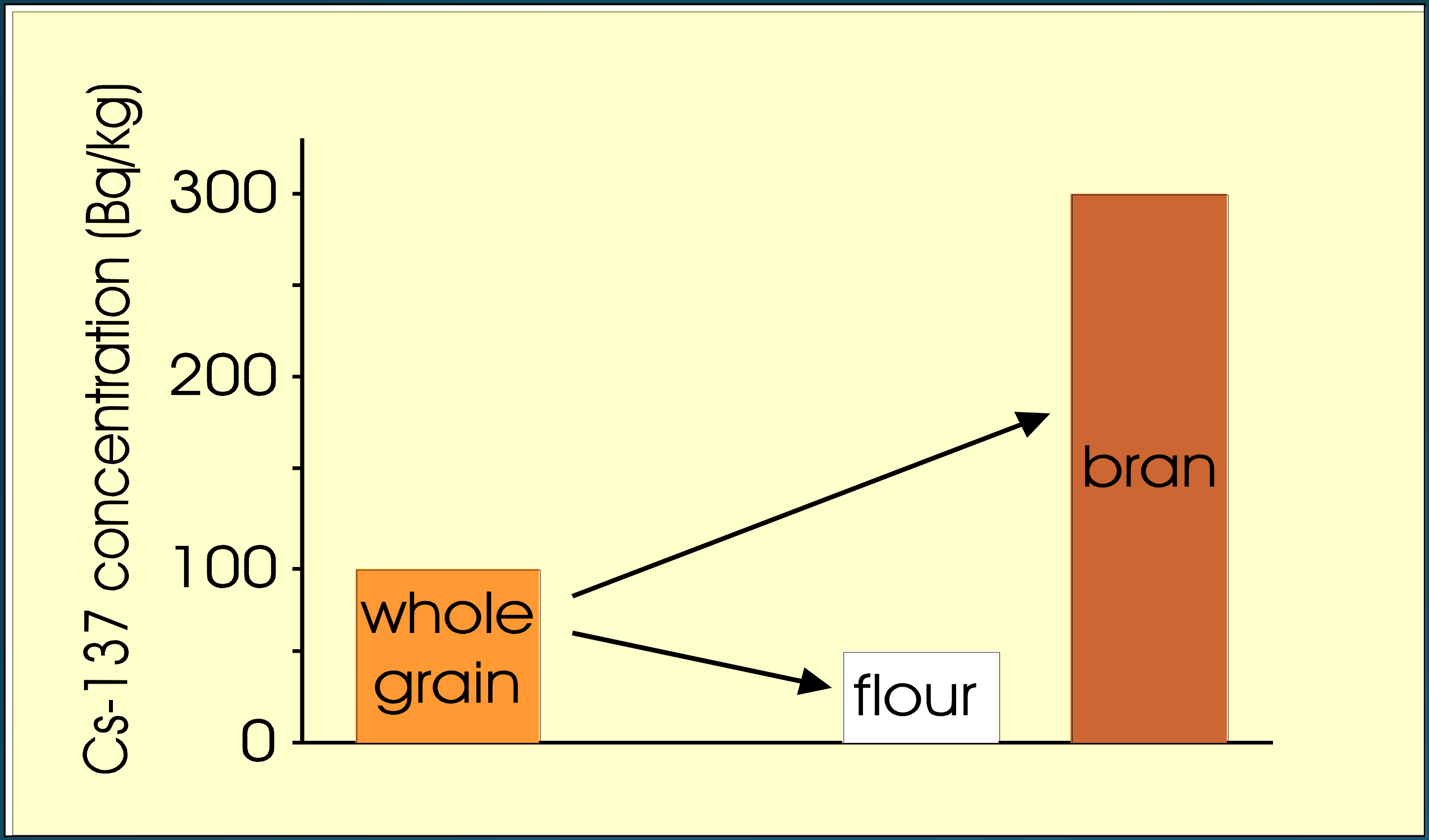
Season dependent feeding regimes

Feeding regimes are linked to the crops cultivated in a region/area

- Specific feeding diets can be simulated in a flexible way
- Allows the modification of feeding regimes for simulating countermeasures



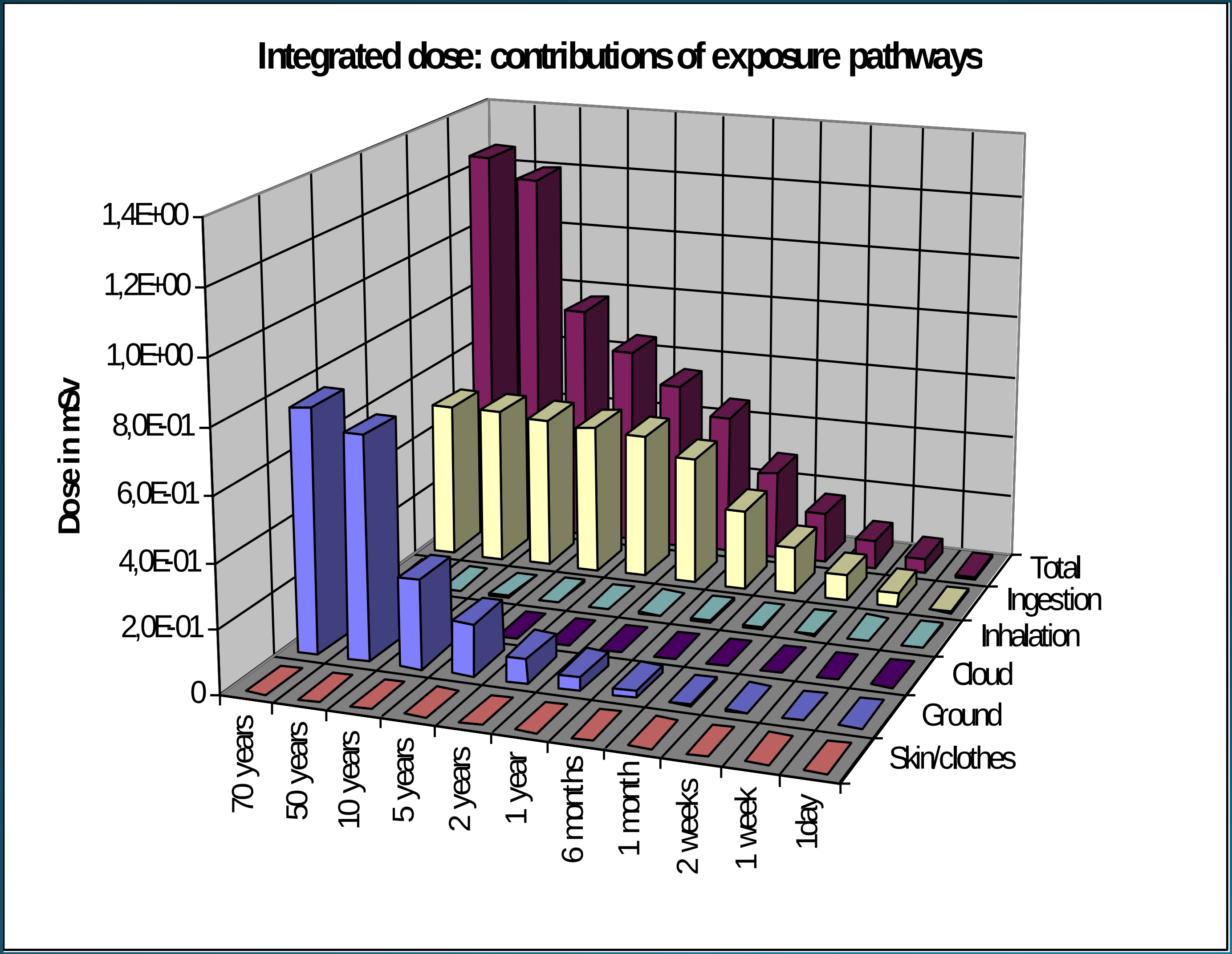
Processing of foodstuffs



Processing factor:
Concentration ratio **Processed product / Raw product**

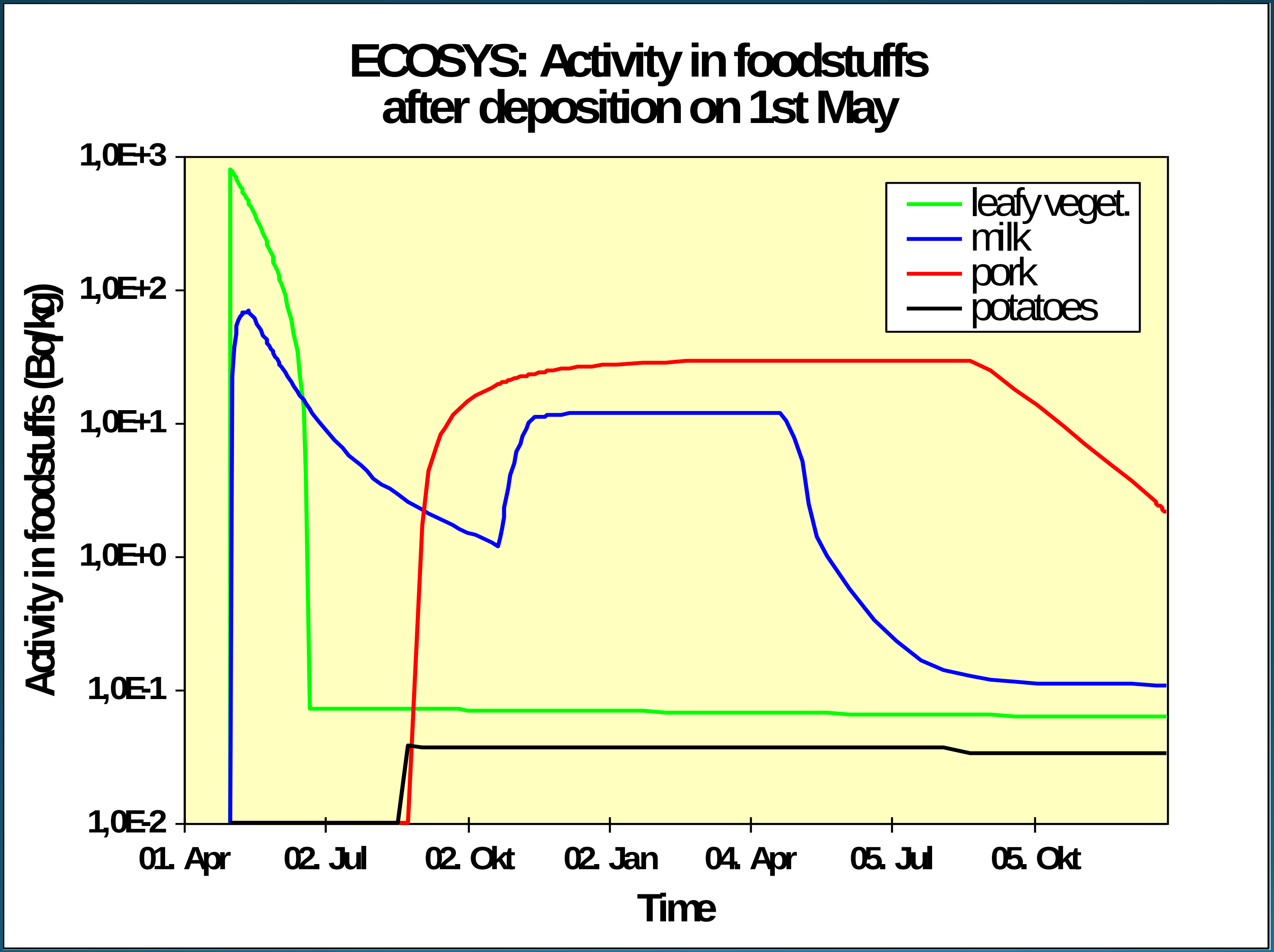
Exemplary results

Doses via different exposure pathways

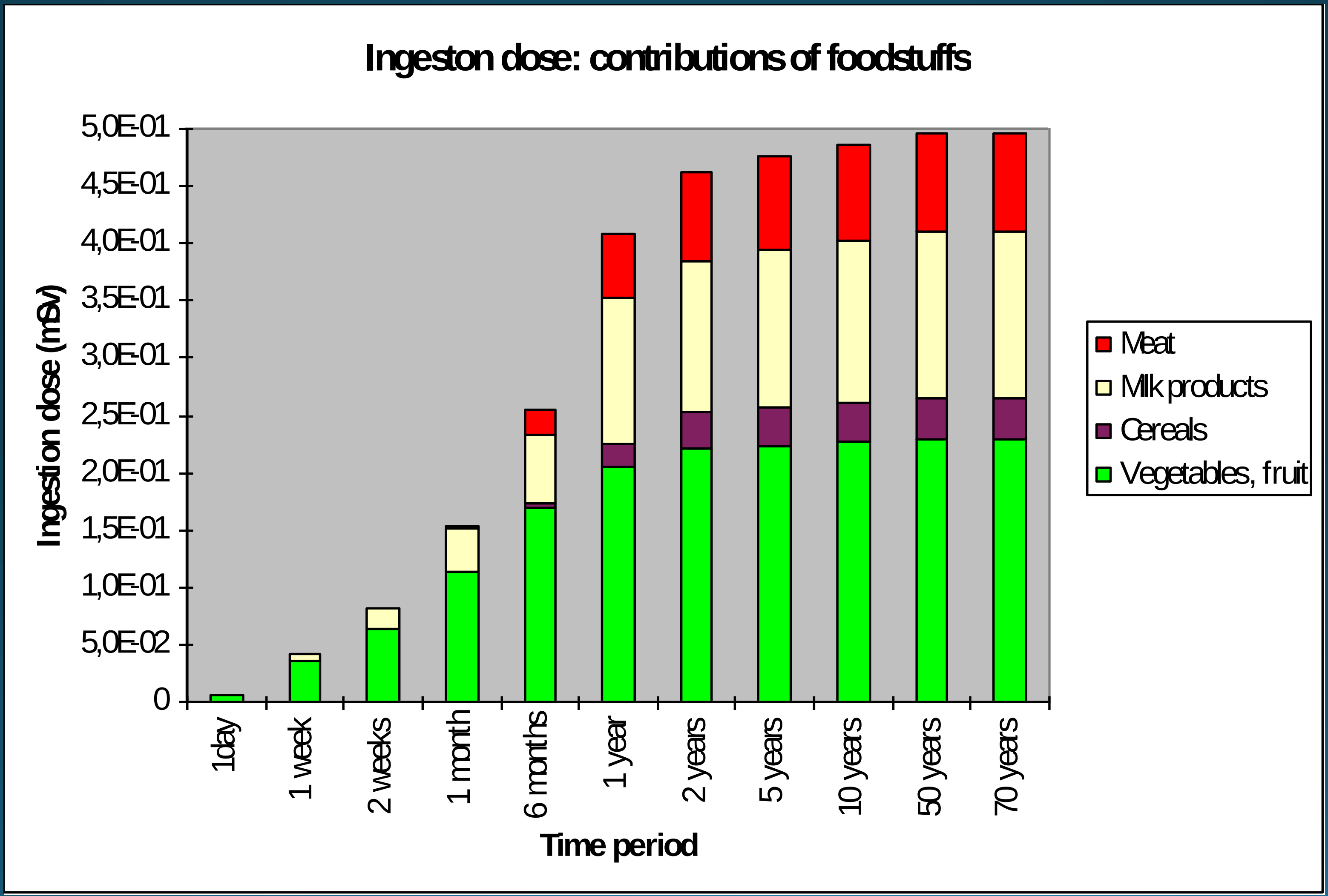


Cs-137-deposition in Munich in April 1986

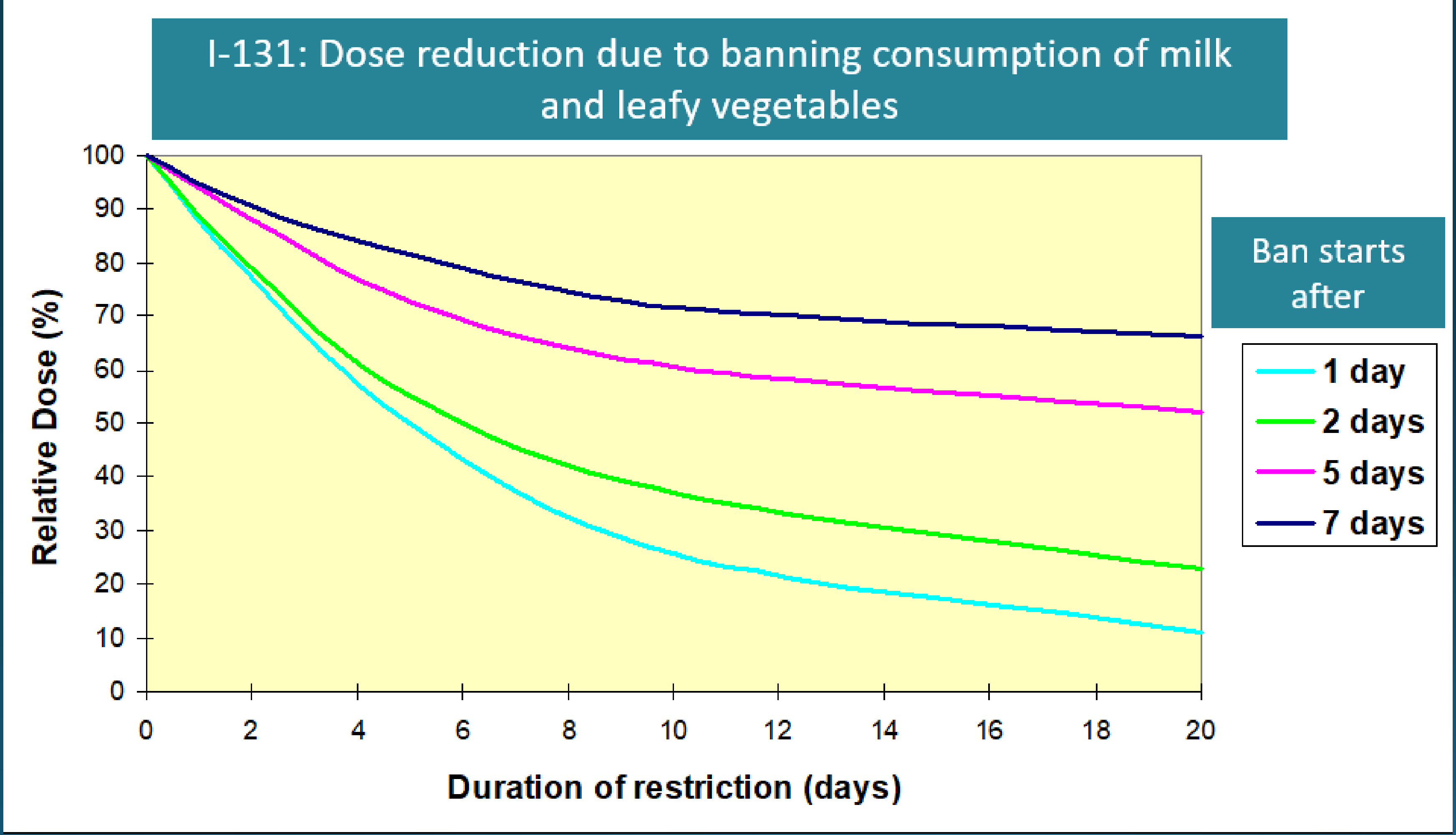
Time-dependent activity in foodstuffs



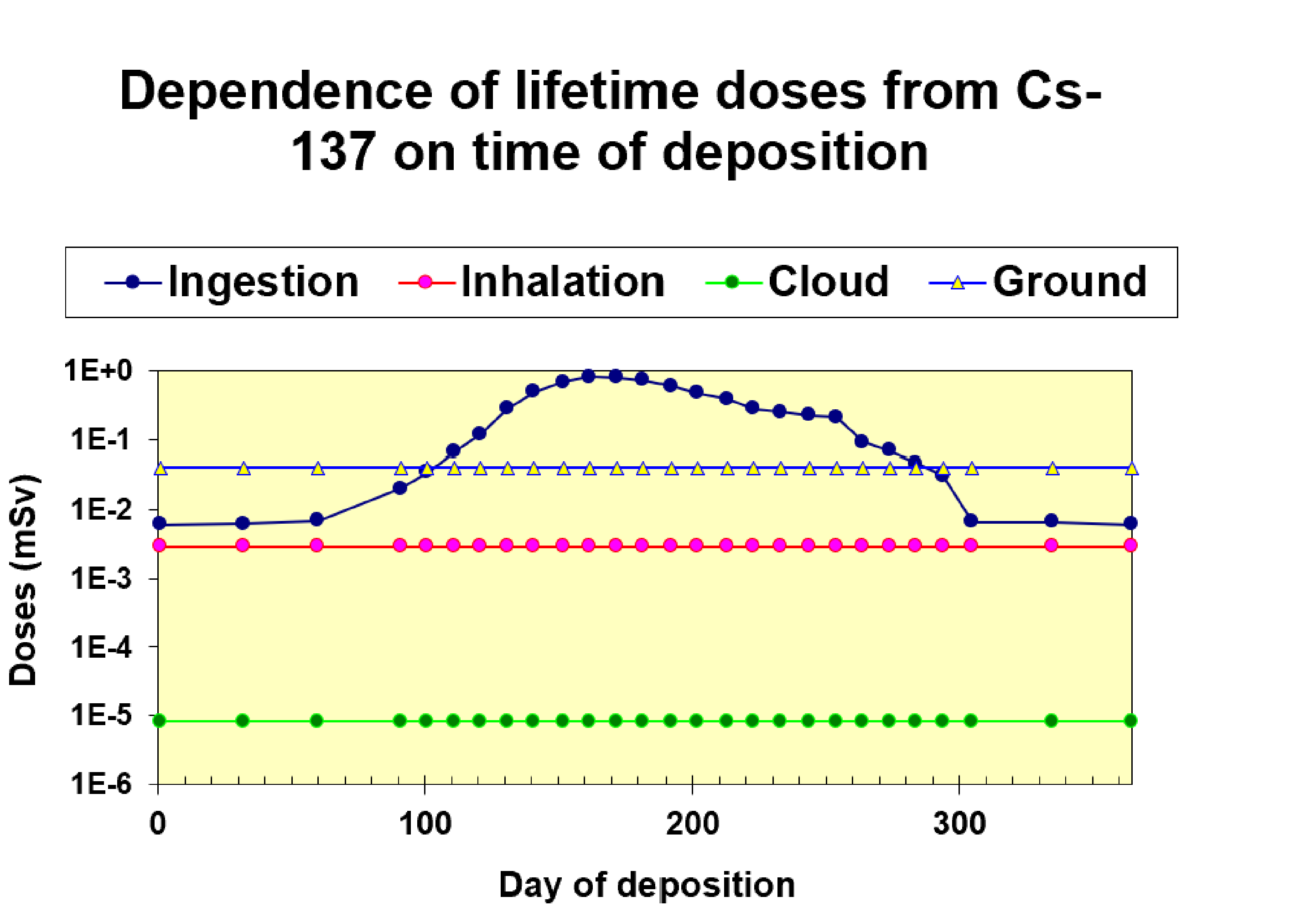
Contribution of foodstuffs to ingestion dose



Simulation of the effectiveness of countermeasures



Dependence of ingestion dose on time of deposition



Dependence of ingestion dose on time of deposition

Germany

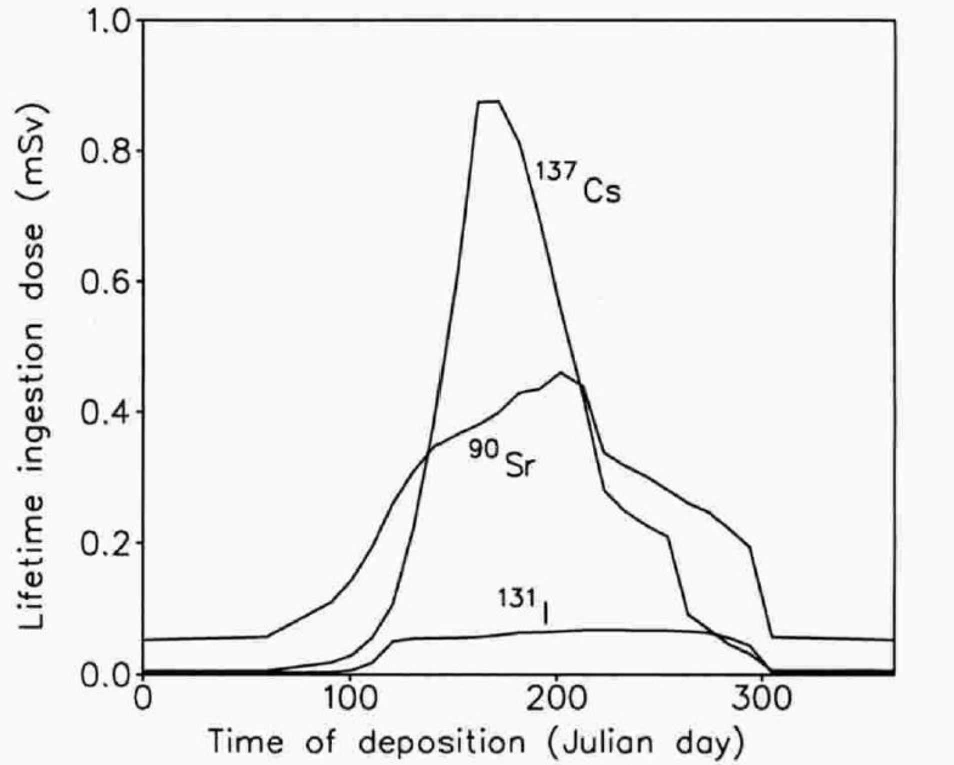


Fig. 6. Dependence of the ingestion dose (integrated over 50 y) on the time of deposition. A time-integrated activity concentration in air of 1×10^6 Bq s m^{-3} for each radionuclide has been assumed.

Hong Kong

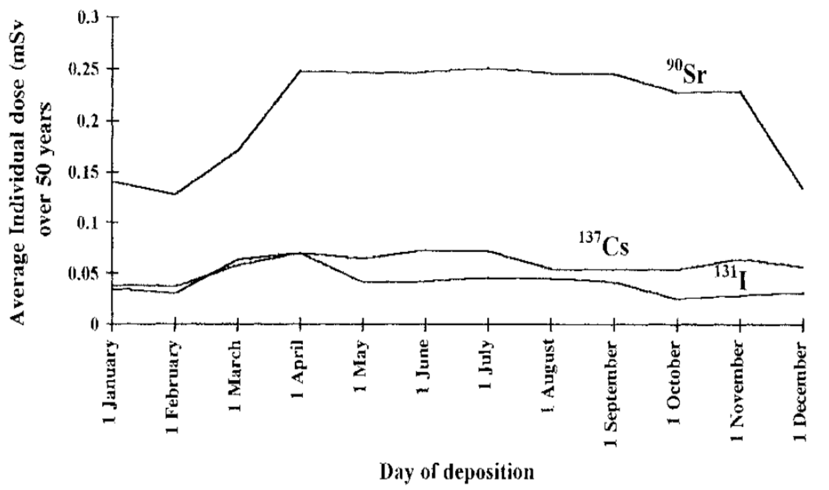


Fig. 2. Variation of the predicted ingestion dose with date of deposition due to an integrated air concentration of 1×10^6 Bq s^{-1} m^{-3} in Hong Kong conditions.

Improving confidence in model results

- **Application of input data**
  - Uncertainty increases with the steps between input and endpoint
  - Prefer input data 'closest' to the endpoint
    - In-vivo measurements: Whole body, thyroid
    - Individual dosimeters

- **Model analysis**
  - Comparison with real data
  - Identification of sensitive assumption and parameters
  - Systematic uncertainty analysis
  - Development of process-oriented models

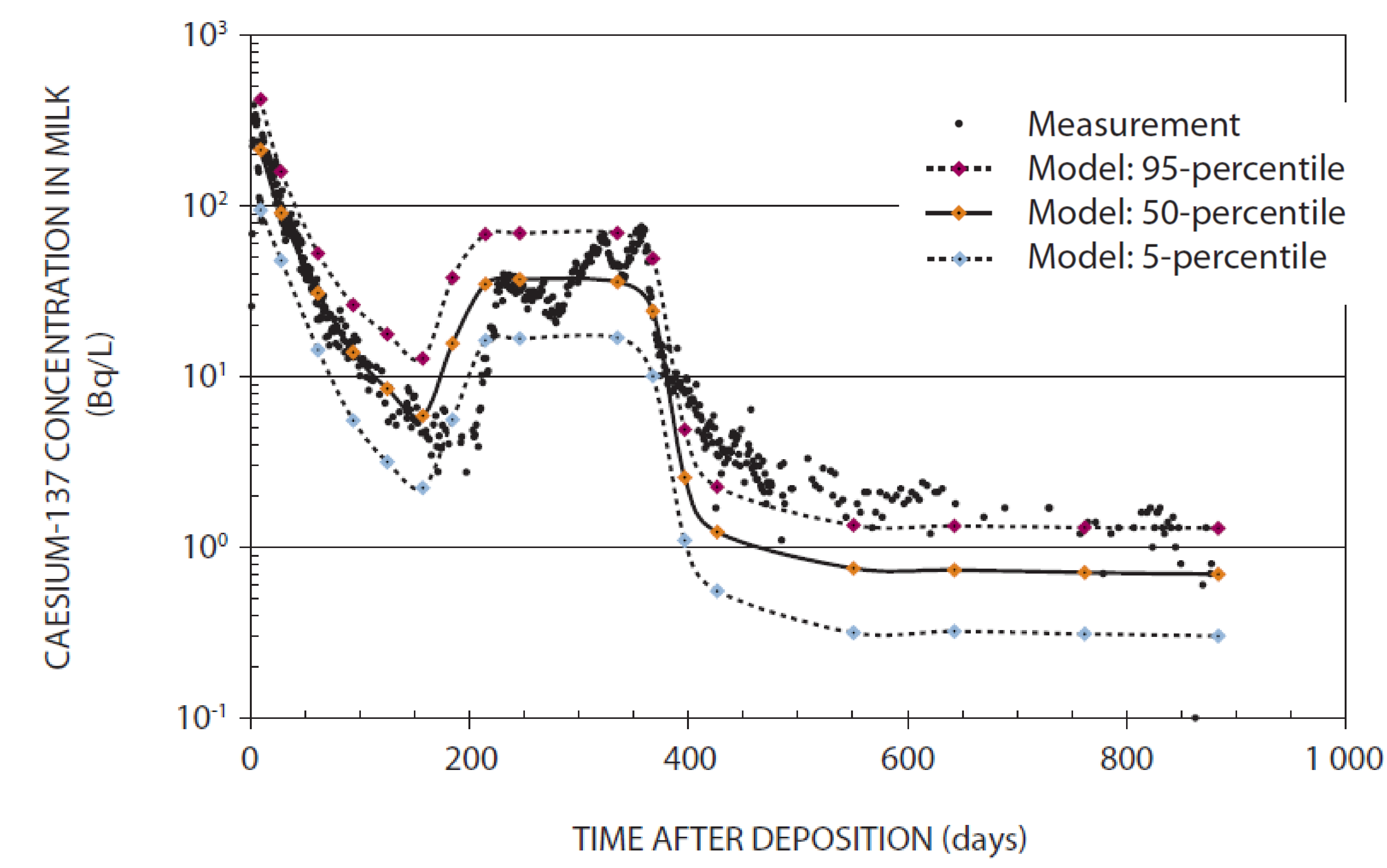
- **Calibration of model with monitoring data**
  - Non-scientists – in general – lack confidence in alone-standing model results

Monitoring and models

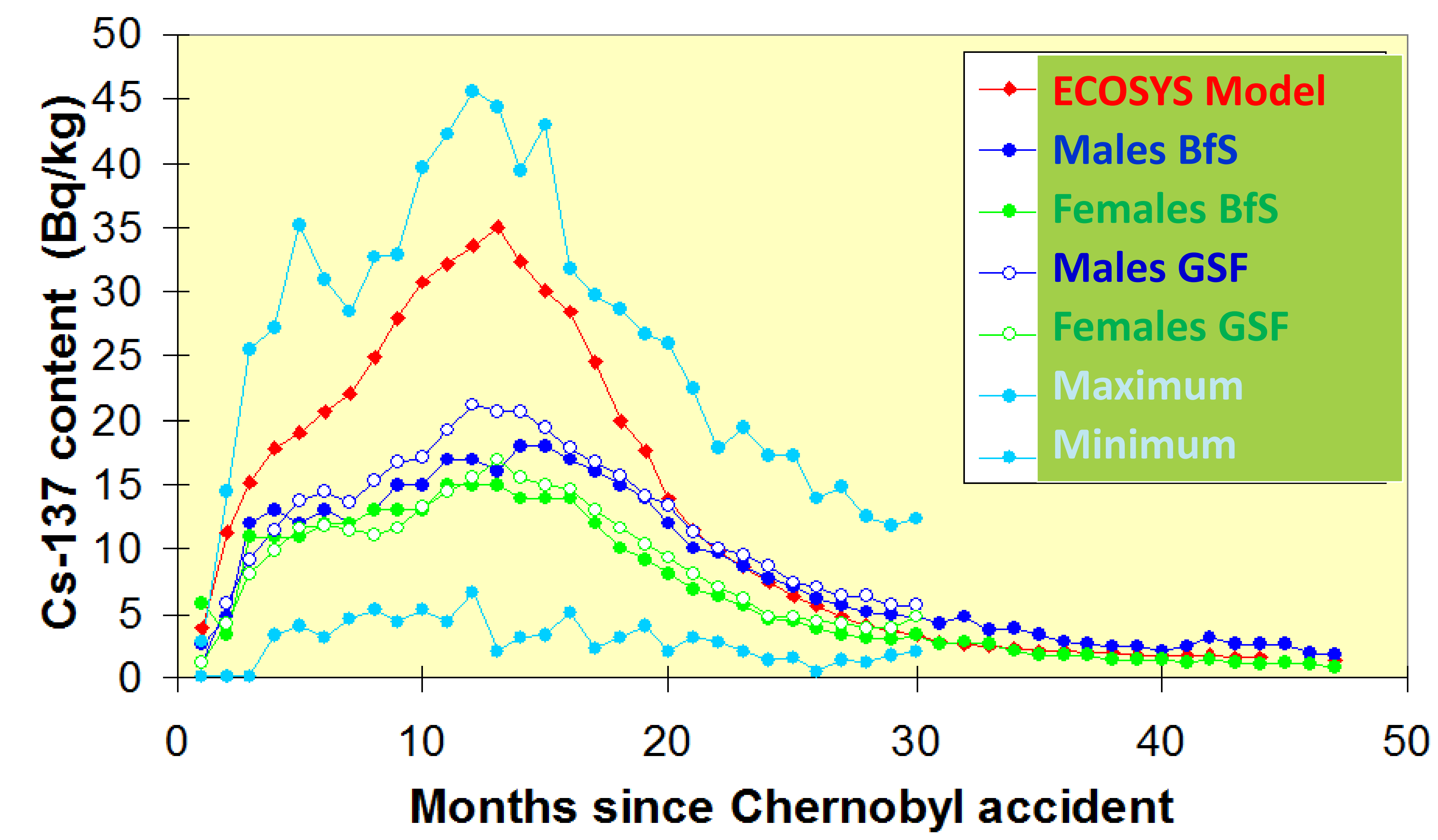
- **Monitoring**
  - Providing measures results
  - Validate and calibrate models
  - But: How representative are measurements?

- **Models**
  - Understand measurements
  - Interpolation in time and space
  - Extrapolation to the future
  - Overcome data gaps

Cs-137 in milk: dairy farm near Munich, Germany, (UNSCEAR, 2008)



Cs-137 whole body counting (near Munich)



Müller, H, and Pröhl, G., The radioecological Model ECOSYS: Concept and Applications, Proc. Intern. Workshop on Improvement of Environmental Transfer Models and Parameters, Tokyo, Japan, 5-6 February, 1996

Suggestions for further development

Lessons from the application of the SPEEDI model

- **System for Prediction of Environmental Emergency Dose Information**
  - Development started in 1980s
  - Triggered by the accident in Three Mile Island

- **Purpose of SPEEDI**
  - To provide forecasts for the diffusion of radioactive materials during a nuclear event
  - Estimation of activity levels in the environment
  - Assessment of doses to people

The use of the SPEEDI model during the Fukushima accident (UNSCEAR 2013)

Table 1. Timeline of events following the earthquake and tsunami

All times are JST

Date	*Reactor*	*Environment*	*Public*	*Workers*
2011-03-11	14:46, EARTHQUAKE			
	Scram in Units 1, 2 and 3 of TEPCO's FDNPS[a]			
	Loss of external electricity			
	15:35, MAJOR TSUNAMI			
	15:37, loss of all electricity, except DC on Unit 3		16:40, MEXT[b] activated SPEEDI[c] and started making daily predictions of concentrations in air and deposition densities for unit release of radioactive material	
	Around 20:00, possible start of damage to reactor core and pressure vessel in Unit 1		20:50, evacuation within 2 km ordered 21:23, evacuation within 3 km ordered 21:23, sheltering from 3 km to 10 km ordered	

Feature

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Fukushima in review: A complex disaster, a disastrous response

Yoichi Funabashi and Kay Kitazawa

Role of the SPEEDI model

- "The system …… **remained largely unused during the crisis**
- ……the Nuclear Safety Commission and MEXT were reluctant to release predictions
  - claiming that the simulated results were based on what several government officials interviewed by our commission called "unreliable emission source term."
- Despite widespread environmental contamination by radioactive material **between March 11 and March 15—the time when the central government made decisions about evacuating residents—SPEEDI data were not officially provided to top leaders in the Prime Minister's Office until March 23**.
- **Evacuation orders were therefore issued without the benefit of SPEEDI forecasts.**
- In hindsight, March 15 turned out to be a crucial turning point; an early morning accident at Unit 2 led to a dramatic rise in the diffusion of radioactive materials from that site. This quashed any hope of containing the radioactivity.
- **SPEEDI was developed in 1984 for exactly this kind of situation; the system was intended to help governments decide precisely when to evacuate residents—and from which specific areas.**
- The failure to use SPEEDI suggests that the heavy investment in time and money to develop this system were for naught.

Problems during the application (cont.)

- **New York Times, 8 August 2011**
  - "In the end, it was the prime minister's office that hid the SPEEDI data," he said.
    "**Because they didn't have the knowledge to know what the data meant, and thus they did not know what to say to the public,** they thought only of their own safety, and decided it was easier just not to announce it."

- **SPEEDI was not properly applied, because**
  - **The users of SPEEDI (MEXT and NSC) didn't trust their own model**
  - **Lack of experience in interpreting model results**
  - **Doubts on the reliability of the results**
  - **Reluctance to approve the official use of model results**
  - **Lacking possibilities for validating the results?**

Suggestions for further developments

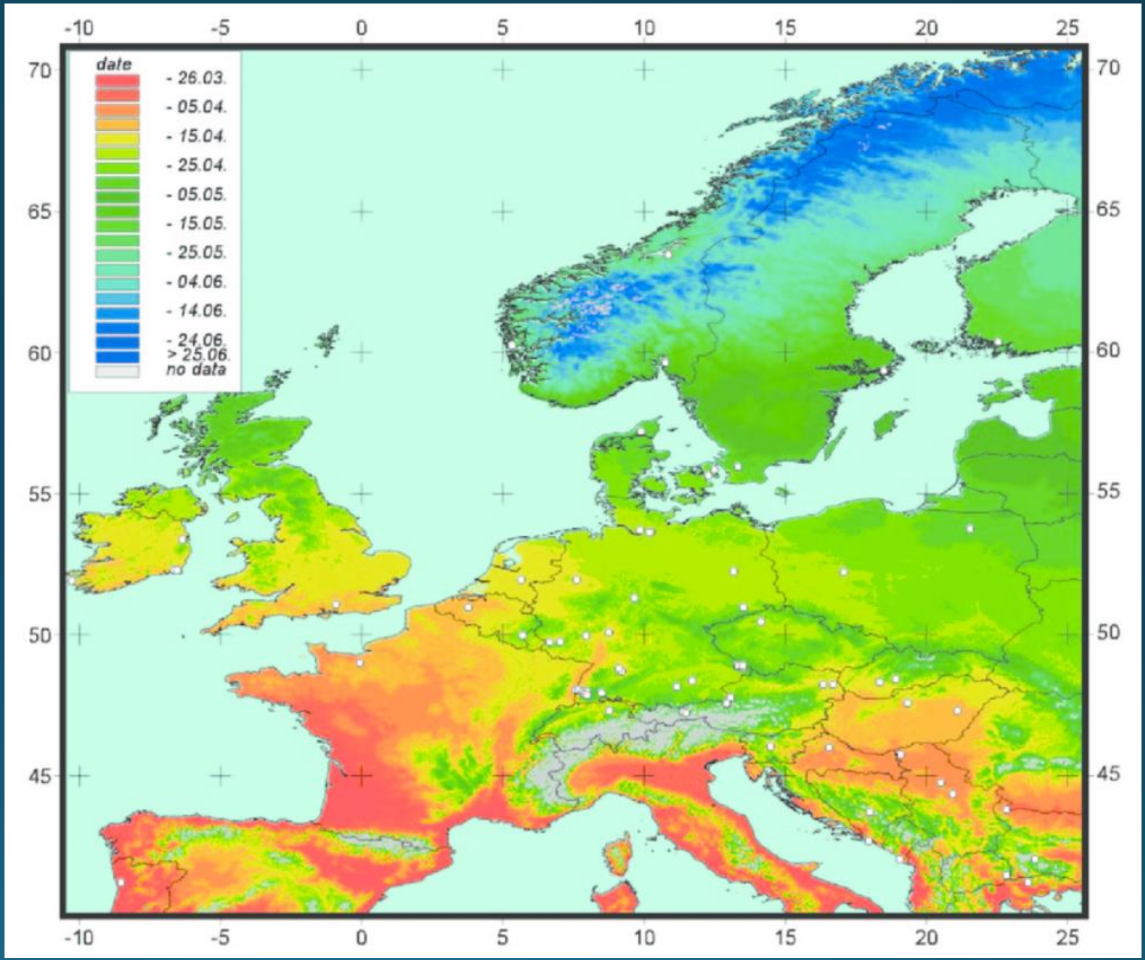
- **Processes**
  - Simple modelling
    - Meanwhile more sophisticated process-based models were developed
    - E.g.: RIP (Radiocaesium Interception Potential)
  - Overly complex modelling may complicate communication of model results

- **Parameters**
  - Collected in the late 1980s/early 1990s
  - Broader data sets are available, thorough review is worthwhile
    - Interception
    - Translocation
    - Transfer soil-plant
    - Feed-animal products
    - Long-term behaviour in soil including migration

Further developments

Revisit underlying scenarios

- –Crops grown
- –Seasonality of growth
- –Feeding regimes
- –Living habits
  - Food intake
  - Life style
  - Ventilation rates
- –Shielding



Average start of growing period in Europe
There are considerable year-to-year variations

Further developments

- **Systematic link to monitoring (if not already implemented)**
  - Key issue as it implicitly validates model results
  - Helps building confidence in models
  - Facilitates communication of model results

- **Key quantities in monitoring**
  - Information on deposition
    - γ-dose rate
    - Results from in-situ spectrometry
    - Activities in soil
  - Activities in continuously harvested/products crops
    - Grass, vegetables
    - Activities in milk
  - Etc. .....

Summary

Advantages

- Flexibility
  - Seasonality, Regionality, Agricultural practice, Life-style
- Simple modelling,
- Application of widely used parameters
- Good performance in validation studies, if exposure conditions are reasonably well defined

Limitations

- Developed in the late 1980s/early 1990
- Data bases require review, if not already done
- Ckeck against process-oriented (sub-)models

Application

- Requires
  - Experience of the user
  - Careful description of the exposure situation
- Link with monitoring results facilitates confidence building

Thank you