# Some Conclusions of the Project BioMoSA for Performance Assessments of Radioactive Waste Disposal

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# What is on the menu ??

- Definition and Objectives of the BioMoSA Project
- Application of the BIOMASS Reference Biosphere Approach
- A Selection of Some of the Results
- Conclusions

# BioMoSA focused on different problems

- 2-year EU 5th framework project (12/2001-11/2003)
- Radioactive waste needs to be isolated from the environment and humans
- Regulatory standards
  - Adequate isolation of radioactive from biosphere and humans
  - Limitation of possible radiological consequences due to hypothetical releases of radionuclides to the environment
- Demonstration of compliance
- Biosphere changes with time: Impact of climate

# In BioMoSA different models were used by different participants

- GSF - Germany*
  - Analytical equations using Excel and Crystal Ball for uncertainty analysis
- CIEMAT - Spain
  - Amber Software (QuantiSci): dynamic compartmental model
- SCK•CEN - Belgium
  - Fortran Software (CVF) (semi-equilibrium model)
- University of Veszprem - Hungary
  - ModelMaker (2000): dynamic compartmental model
- Studsvik EcoSafe - Sweden
  - PRISM Windows 5.0 (Studsvik Eco & Safety AB's (EcoSafe) tool)

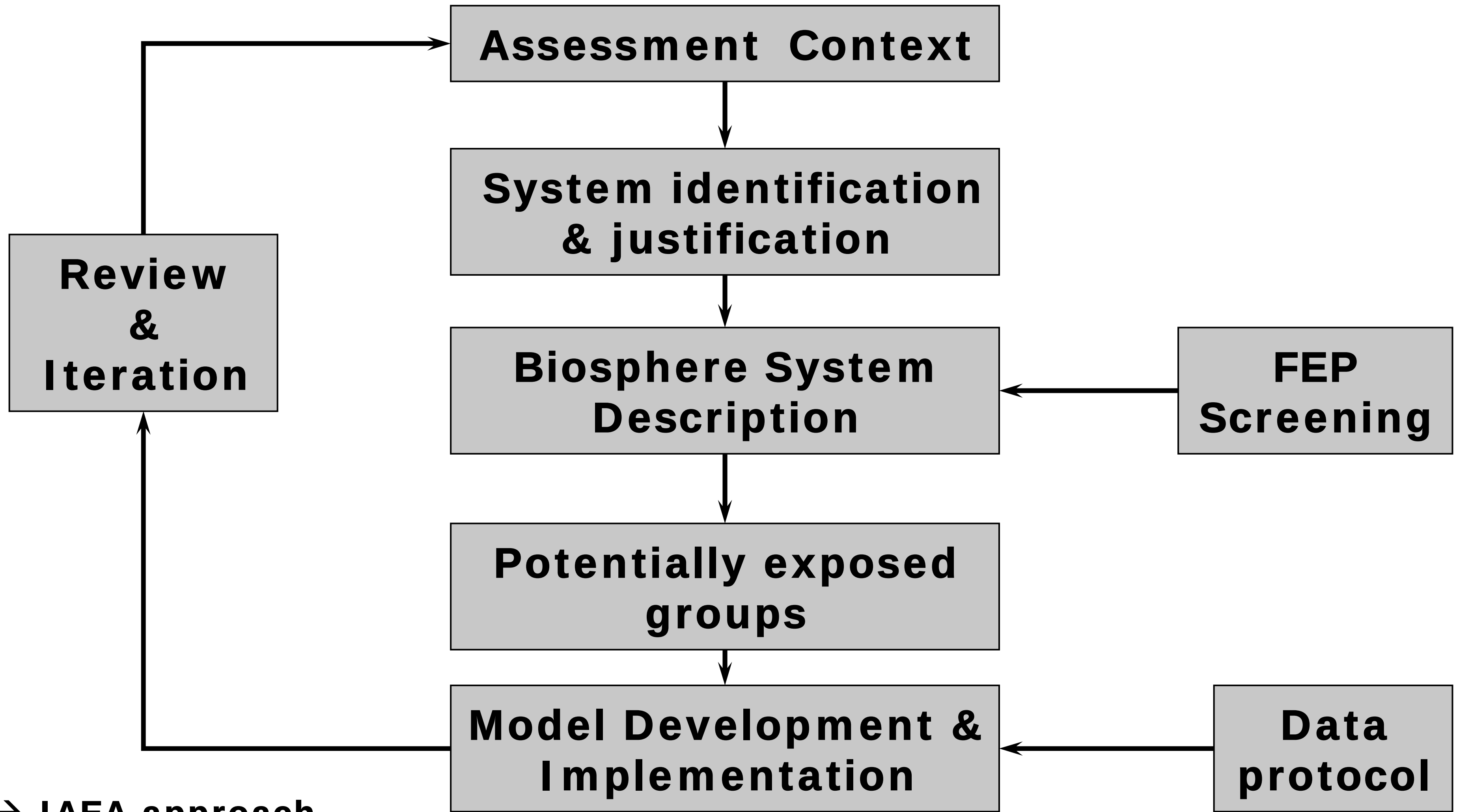


* Coordinator

# The EU BioMoSA project wanted to give confidence to the public

- Objectives:
  - Development of site-specific biosphere models for 5 sites in Europe using the BIOMASS Reference Biosphere Methodology
  - Comparison of structure, results and uncertainties
  - Development of a generic biosphere assessment tool
  - Compare site-specific and generic models
  - Identify relevant site-specific and generic features, events and processes

# The BIOMASS Reference Biosphere Methodology is used




→ **IAEA approach**

# The assessment context can be subdivided in 8 different steps

- Assessment purpose
- Assessment endpoints
- Assessment philosophy
- The type of repository system
- The site context
- Source terms and the geosphere-biosphere interface
- Societal assumptions
- Time frames

# The assessment was performed as realistic as possible

- Present day conditions
  - Technology, society, living habits
- Radionuclides (incl. daughters)
  - Cl-36, Se-79, Tc-99, I-129, Cs-135, Ra-226, Pa-231, Np-237, U-238, Pu-239
- Time frame
  - 90 % of equilibrium in soil achieved
- Annual effective doses
  - infants and adults
  - Uncertainty of doses

# 5 different sites were considered

- Hungary:
  - Intensive agriculture
  - Cold winters, hot summers
  - Pronounced rain deficit during the vegetation period
- Spain
  - Extensive land use
  - Mild winters, hot and very dry summers
- Belgium and Germany
  - Intensive agriculture
  - Mild winters, cool summers
  - Low to moderate precipitation deficit
- Sweden
  - Extensive agriculture
  - Cold winters and cool summers
  - Little precipitation deficit

# Different geosphere biosphere interfaces were considered at different location

| | | |
|---|---|---|
| • Belgium | → | <u>well</u>, river |
| • Germany | → | <u>well</u> |
| • Hungary | → | <u>well</u>, lake |
| • Spain | → | <u>well</u>, dam, river, |
| | → | sub-surface soil |
| • Sweden | → | <u>well</u>, lake |
| | → | sub-surface soil |
| • Generic | → | all possible interfaces |

# Within the system identification and justification itself some enquiries are made as well

Biosphere system pre-defined by explicit legislation or guidance ?

No →

Yes ↓

Biosphere system change to be considered ?

No →

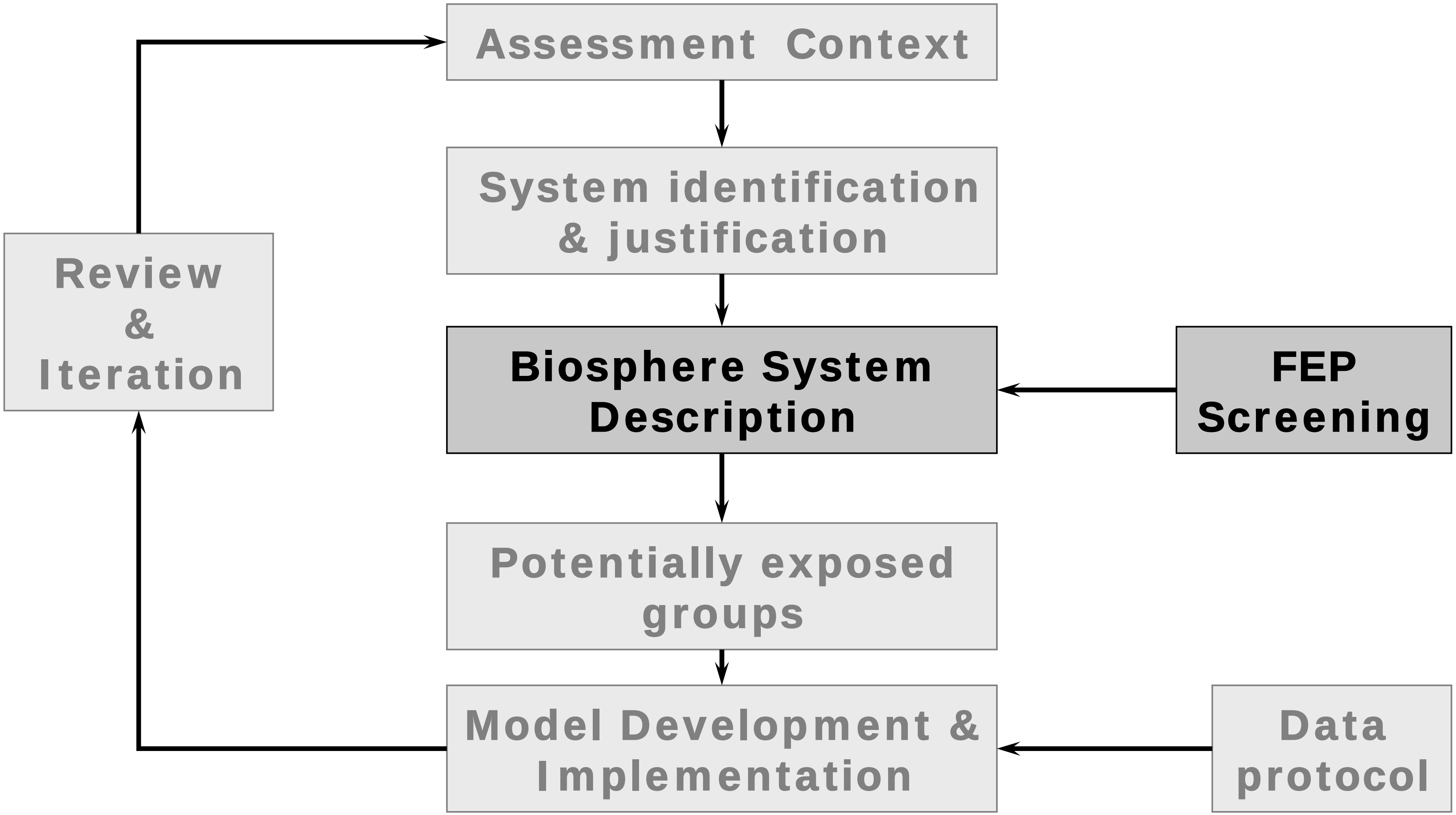
Yes ↓

Select approach to represent biosphere system change

Sequential →

Non-sequential ↓

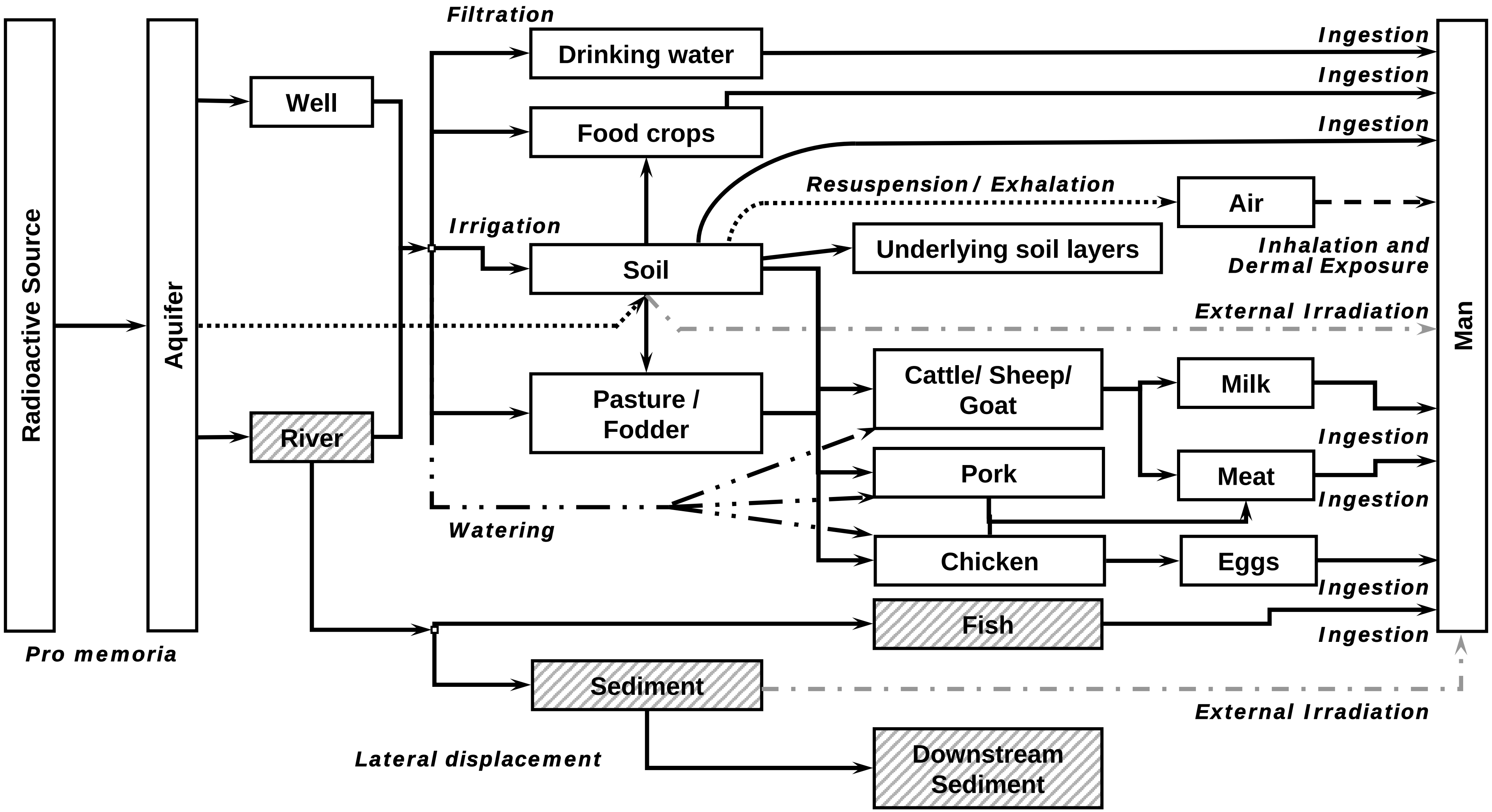
# The Biosphere System screening is based on expert judgement



# Interrelationships between compartments are visualised thanks to an interaction matrix

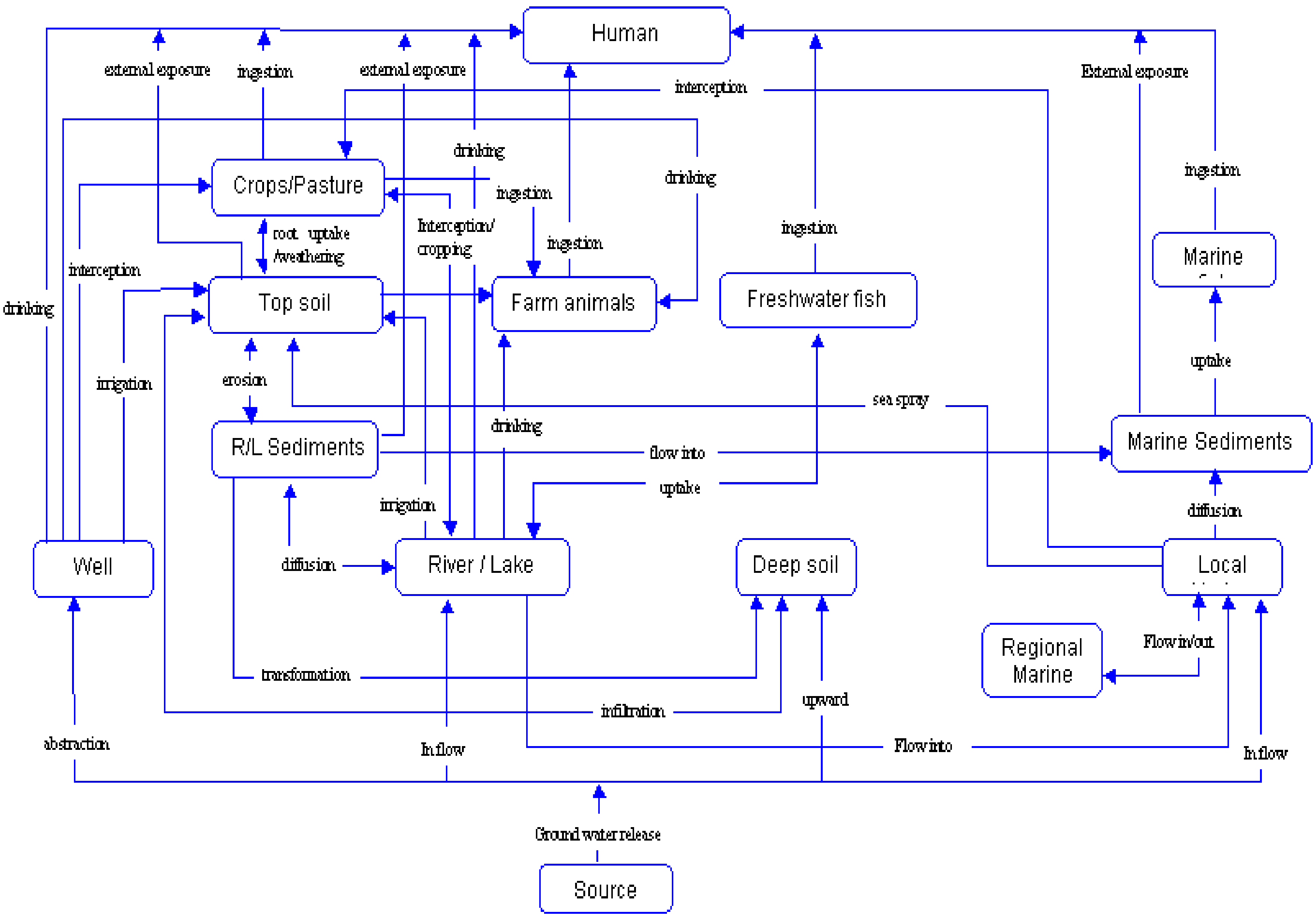
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Well | | | Irrigation | Irrigation , interception, translocation | Irrigation, interception | Intake: Watering | | | Ingestion |
| 2 | | River | | Water supply by irrigation | Irrigation , interception, translocation | Irrigation, interception | Intake: Watering | | | Ingestion (after filtration) |
| 3 | | | Underlying Soil layers | Upwelling | | | | | | |
| 4 | | | Infiltration | Soil root zone | Root uptake (transpiration of $^3H$, uptake of $^{14}CO_2$) | Root uptake (transpiration of $^3H$, uptake of $^{14}CO_2$) | Soil intake | | Resuspension or exhalation (+emanation of Rn) | External irradiation and ingestion |
| 5 | | | | Weathering | Food crops | | | | | Ingestion |
| 6 | | | | Weathering | | Pasture | Intake | | | |
| 7 | | | | | | | Animal | Animal metabolism | | |
| 8 | | | | | | | | Milk / meat / eggs | | Ingestion |
| 9 | | | | | | | | | Air | Inhalation and Dermal Exposure |
| 10 | | | | | | | | | | Man |

# A conceptual model is built based on the interaction matrix



# A generic model was developed by NRPB

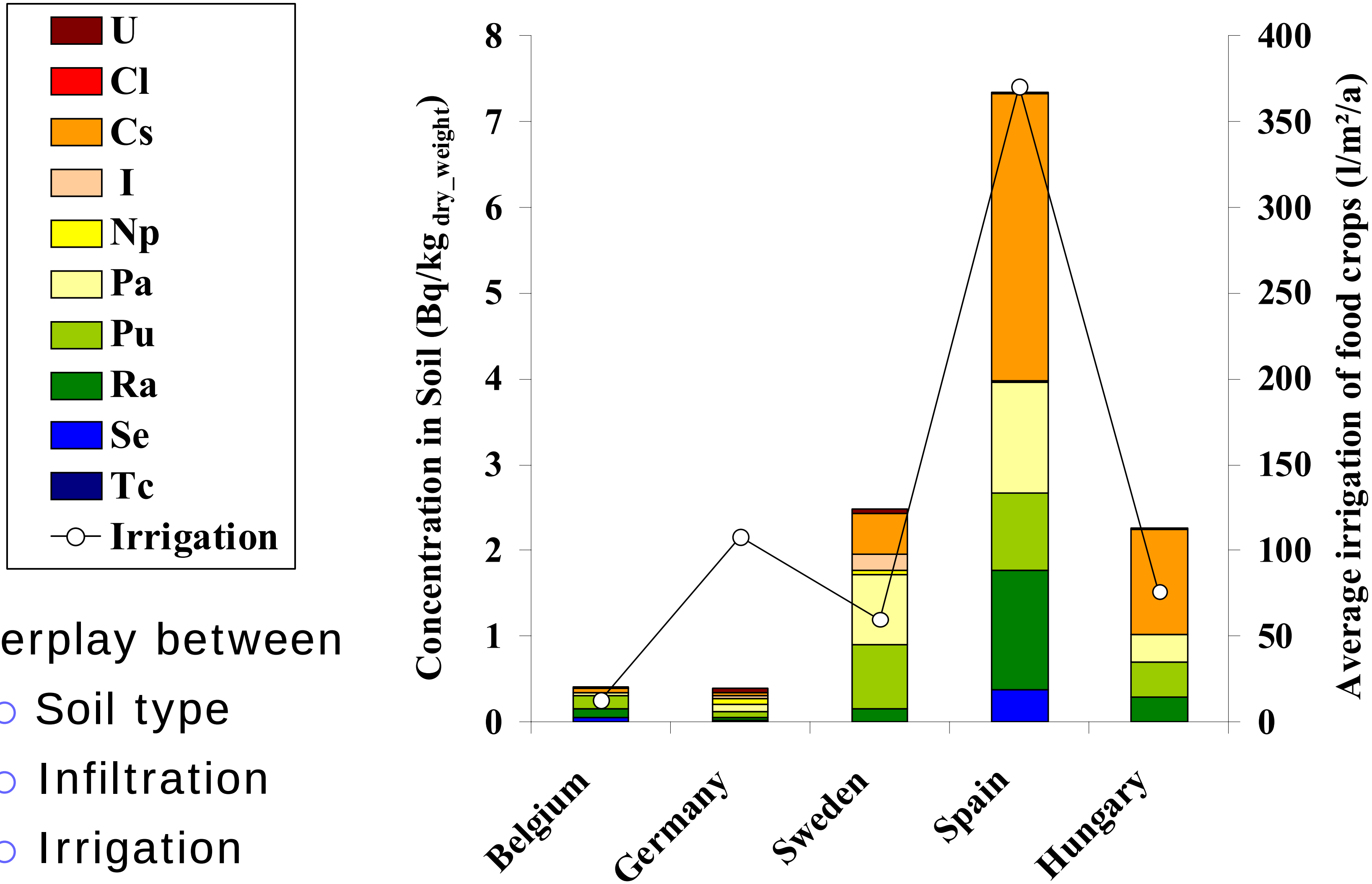
- Development of a generic model
  - Contains all FEPs
  - Contains all Geosphere-Biosphere-Interfaces
- Comparison against site-specific models
- Identification of important pathways
- Suggestions for model simplification


Human
external exposure
ingestion
external exposure
interception
External exposure
drinking
drinking
Crops/Pasture
ingestion
ingestion
root uptake
/weathering
Interception/
cropping
ingestion
ingestion
interception
drinking
Top soil
Farm animals
Freshwater fish
Marine
irrigation
erosion
uptake
sea spray
drinking
R/L Sediments
flow into
Marine Sediments
uptake
irrigation
diffusion
Well
diffusion
River / Lake
Deep soil
Local
Regional
Marine
Flow in/out
transformation
infiltration
upward
abstraction
In flow
Flow into
In flow
Ground water release
Source

# Different exposure pathways were modelled

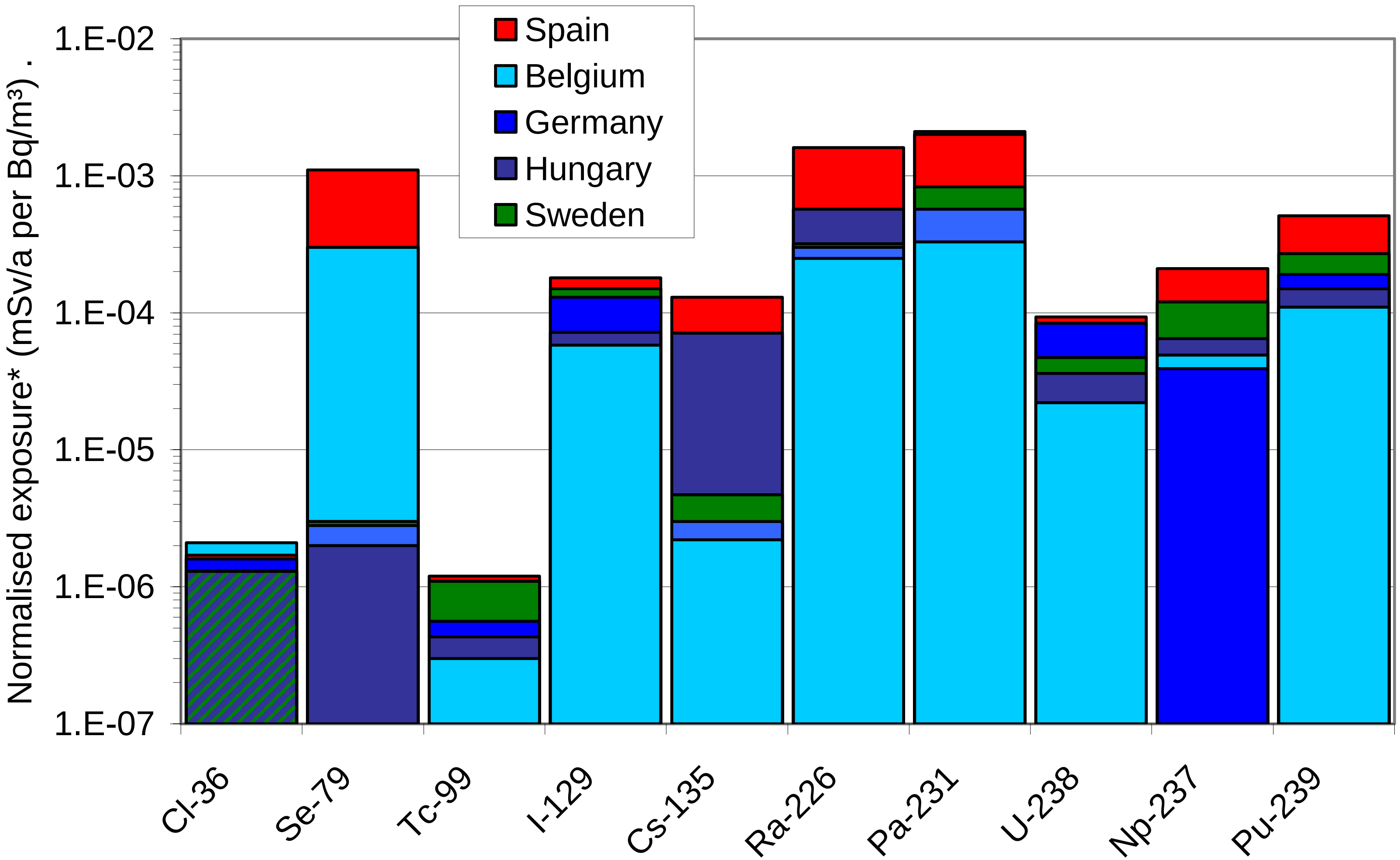
- Ingestion
  - Drinking water for humans
  - Watering cattle
  - Irrigation of crops
  - Fish consumption
- Inhalation of contaminated dust/radon
- External exposure
  - Contaminated arable land
  - Contaminated river/sediments

# Contamination of the soil depends on the irrigation



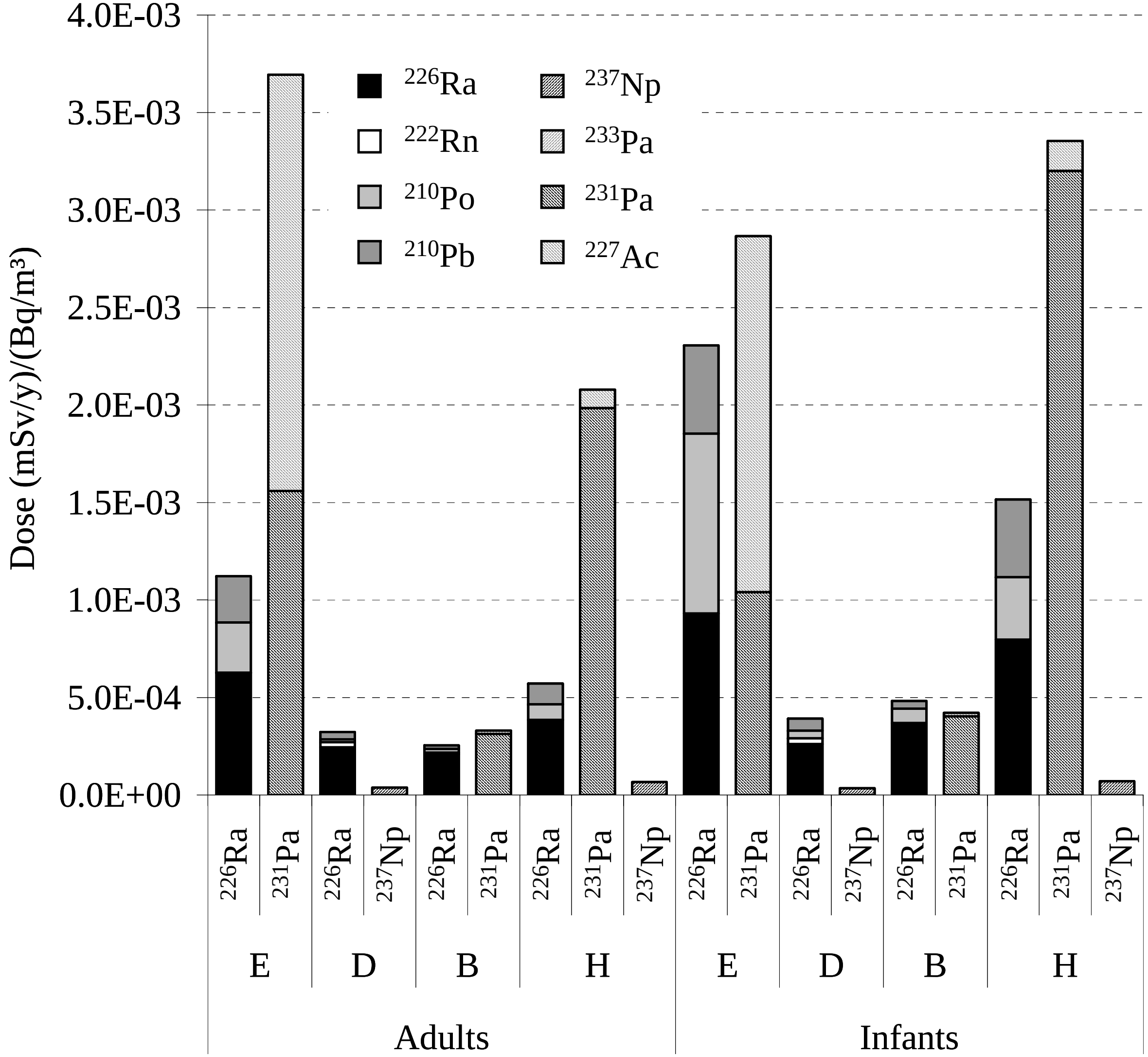

- Interplay between
  - Soil type
  - Infiltration
  - Irrigation

# Deterministic calculations were performed for all sites

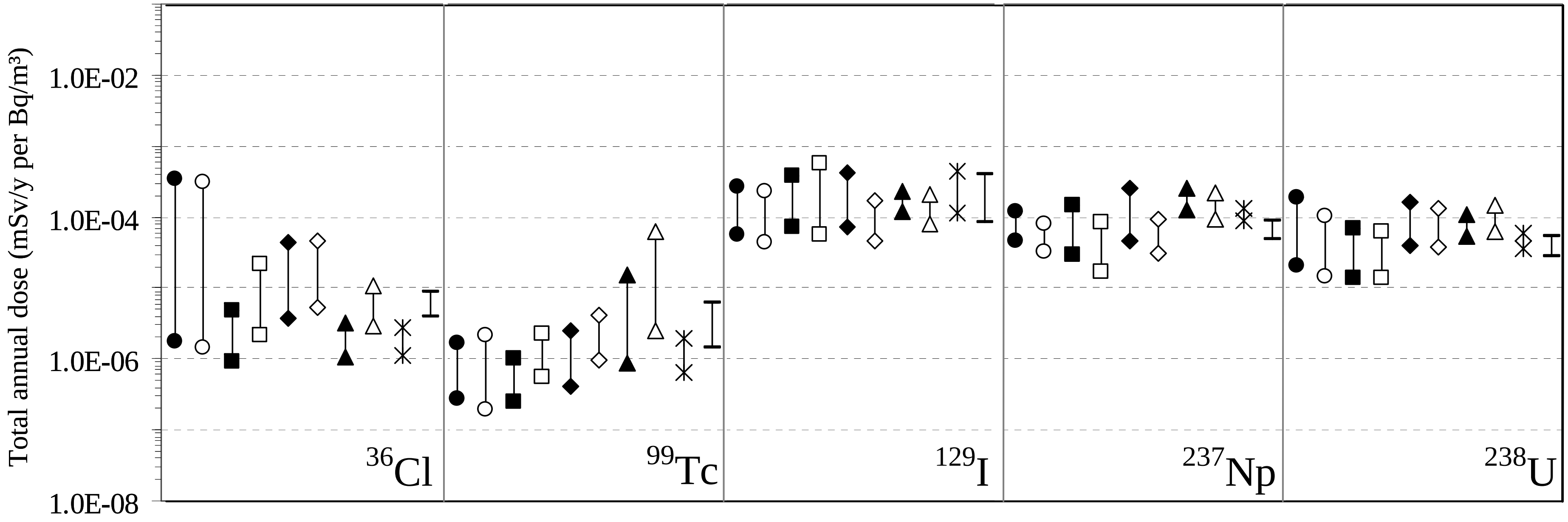



** Normalized exposure to adults for the well scenario*

# ‘Local’ aspects are influencing the dose of the daughter

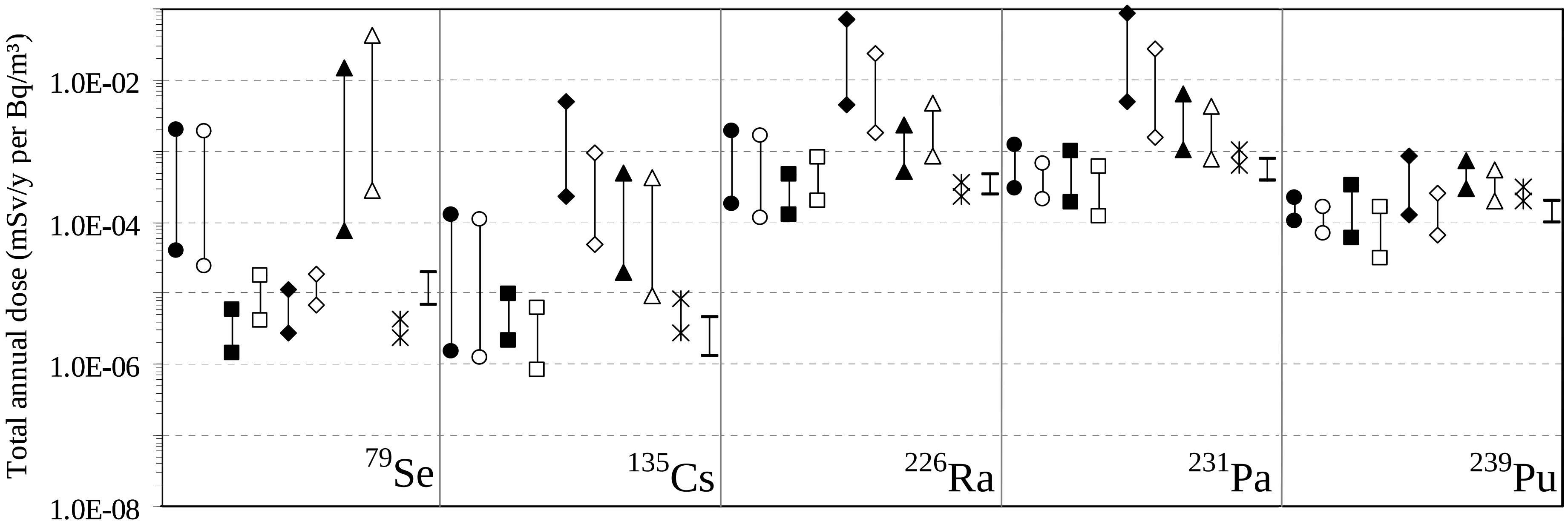


# Differences between age groups are mostly limited



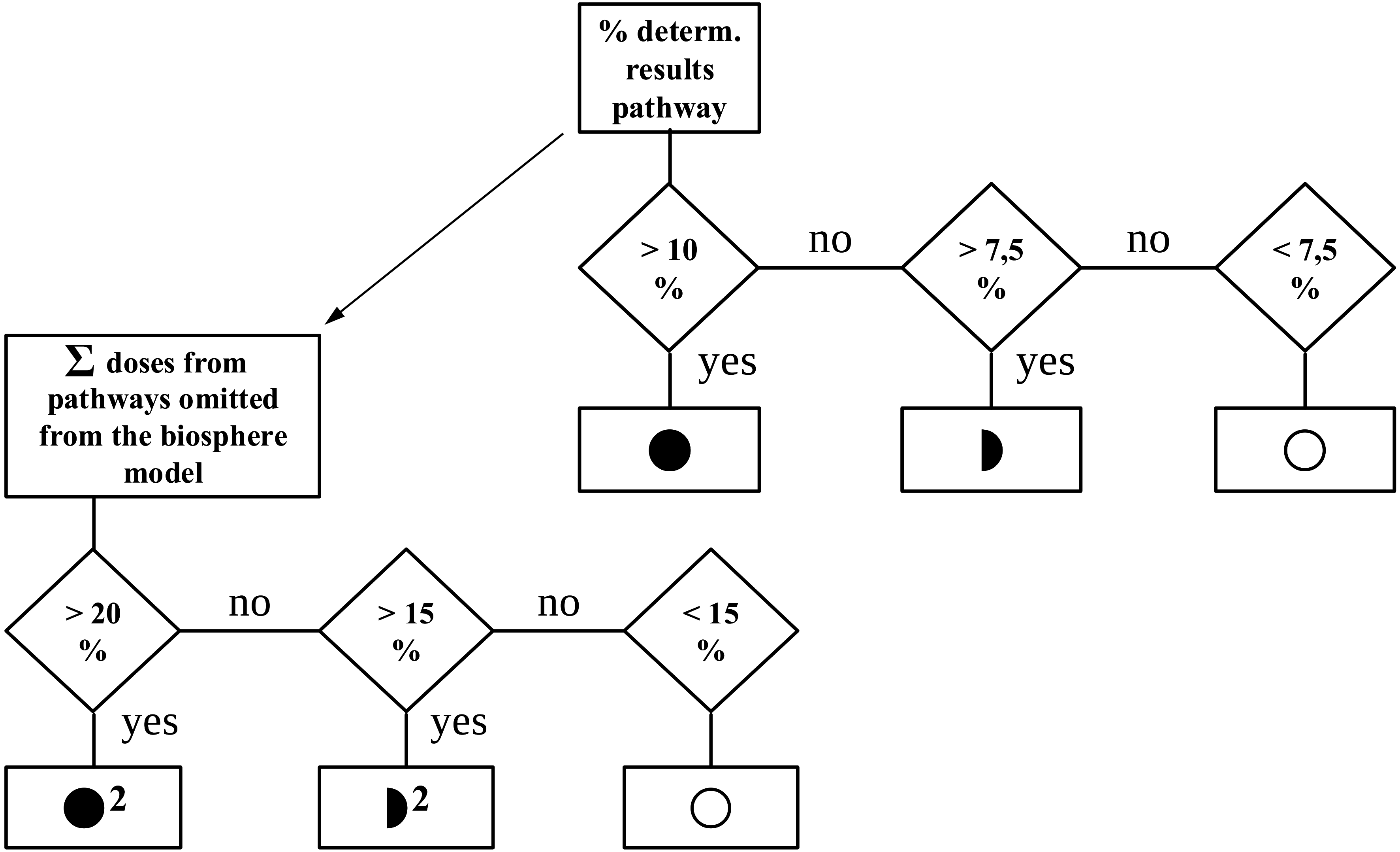

Belgium (adult: ●/infant: ○), Germany (adult: ■/infant: □), Hungary (adult: ◆/infant: ◇), Spain (adult: ▲/infant: △) and Sweden (adult: ∗/infant: –)

# Sometimes large differences are found between models




Belgium (adult: ●/infant: ○), Germany (adult: ■/infant: □), Hungary (adult: ◆/infant: ◇), Spain (adult: ▲/infant: △) and Sweden (adult: ∗/infant: –)

# Making a distinction between important and less important pathways is necessary



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# The importance of pathways depends on the critical group (1/2)

| Pathway | Adults | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $^{36}$Cl | $^{79}$Se | $^{99}$Tc | $^{129}$I | $^{135}$Cs | $^{226}$Ra | $^{231}$Pa | $^{238}$U | $^{237}$Np | $^{239}$Pu |
| Drinking water, ing. | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| Fish, ing. | ○ | ● | ○ | ○ | ◖ | ○ | ○ | ○ | ○ | ○ |
| Soil, ext. exposure | ○ | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ |
| Soil, ing. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Leafy veget., ing. | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| Fruit veget., ing. | ●[2] | ●[2] | ● | ●[2] | ● | ● | ● | ○ | ◖ | ○ |
| Cereals, ing. | ● | ◖ | ● | ● | ● | ● | ● | ● | ● | ● |
| Root crops, ing. | ● | ● | ● | ● | ● | ● | ● | ○ | ○ | ○ |
| Cow's milk, ing. | ● | ○ | ○ | ● | ● | ○ | ○ | ○ | ○ | ○ |
| Beef, ing. | ● | ● | ○ | ◖ | ● | ○ | ○ | ○ | ○ | ○ |
| Mutton/Lamb, ing. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Pork, ing. | ● | ● | ○ | ○ | ● | ● | ○ | ● | ● | ○ |
| Chicken/birds ing. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Citrus, ing. | ○ | ○ | ○ | ○ | ●[2] | ●[2] | ○ | ○ | ○ | ○ |
| Fruit, ing. | ●[2] | ●[2] | ● | ●[2] | ●[2] | ● | ● | ◖ | ●[2] | ◖ |
| Legumes, ing. | ● | ○ | ● | ● | ○ | ◖ | ● | ● | ● | ● |
| Eggs, ing. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Air, inhalation | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ● |

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# The importance of pathways depends on the critical group (2/2)

| Pathway | Infants | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $^{36}$Cl | $^{79}$Se | $^{99}$Tc | $^{129}$I | $^{135}$Cs | $^{226}$Ra | $^{231}$Pa | $^{238}$U | $^{237}$Np | $^{239}$Pu |
| **Drinking water, ing.** | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| **Fish, ing.** | ○ | ○ (red) | ○ | ○ | ○ (red) | ○ | ○ | ○ | ○ | ○ |
| **Soil, ext. exposure** | ○ | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ |
| **Soil, ing.** | ○ | ○ | ○ | ○ | ○ | ○ | ● (red) | ○ | ○ | ● (red) |
| **Leafy veget., ing.** | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| **Fruit veget., ing.** | ○ (red) | ○ (red) | ◖ (red) | ○ (red) | ● | ● | ● | ◖ (red) | ◖ | ◖ (red) |
| **Cereals, ing.** | ● | ● (red) | ● | ● | ○ (red) | ● | ● | ● | ● | ● |
| **Root crops, ing.** | ● | ● | ● | ● | ● | ● | ● | ◖ (red) | ◖ (red) | ◖ (red) |
| **Cow's milk, ing.** | ● | ● (red) | ● (red) | ● | ● | ● (red) | ○ | ○ | ○ | ○ |
| **Beef, ing.** | ● | ● | ○ | ○ (red) | ● | ● (red) | ○ | ○ | ○ | ○ |
| **Mutton/Lamb, ing.** | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| **Pork, ing.** | ● | ● | ○ | ○ | ● | ○ (red) | ○ | ● | ● | ○ |
| **Chicken/birds ing.** | ○ | ● (red) [2] | ○ | ○ | ● (red) [2] | ○ | ○ | ○ | ○ | ○ |
| **Citrus, ing.** | ○ | ● (red) | ◖ (red) | ○ | ● (red) | ● (red) | ● (red) [2] | ○ | ○ | ○ |
| **Fruit, ing.** | ● (red) | ● (red) | ● | ● (red) | ● (red) | ● | ● | ● (red) | ● (red) | ● |
| **Legumes, ing.** | ◖ (red) | ○ | ● | ● | ○ | ○ (red) | ○ (red) | ● | ● | ● |
| **Eggs, ing.** | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| **Air, inhalation** | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ● |

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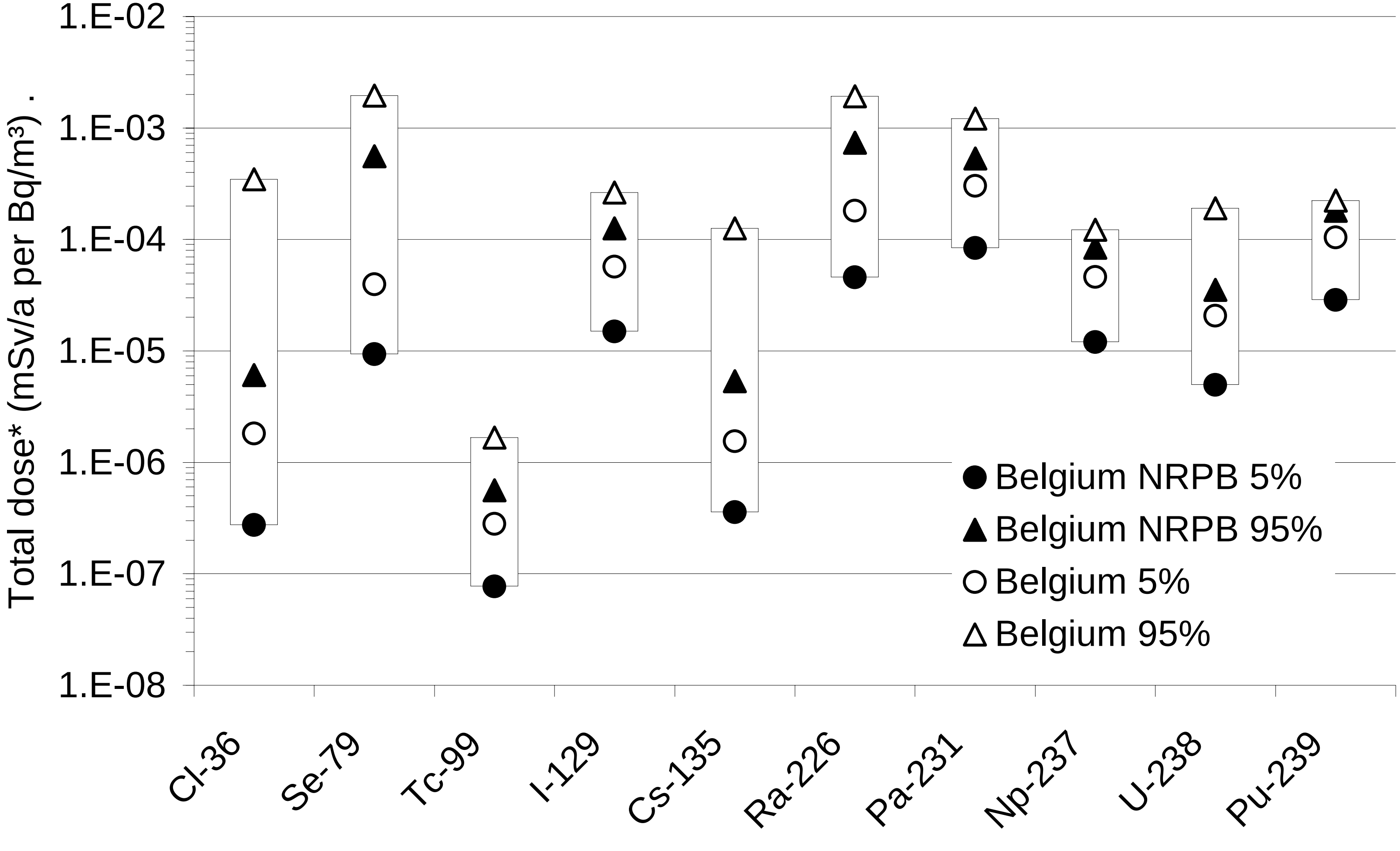
# Irrigation, soil-plant transfer factor and soil distribution factor are most important

| | | | $^{36}Cl$ | $^{79}Se$ | $^{99}Tc$ | $^{129}I$ | $^{135}Cs$ | $^{226}Ra$ | $^{231}Pa$ | $^{238}U$ | $^{237}Np$ | $^{239}Pu$ | $^{210}Pb$ | $^{210}Po$ | $^{222}Rn$ | $^{227}Ac$ | $^{233}Pa$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hungary | Adults | 1e | $Kd_s$ | $Q^{prk}$ | $\kappa$ | $Q^{mlk}$ | $Kd_s$ | $\eta_{Rn}$ | $Kd_s$ | $Kd_s$ | $Q^{lv}$ | $Q^{lv}$ | $\kappa$ | $\kappa$ | $\eta_{Rn}$ | $B_v^{fv}$ | $\kappa$ |
| | | 2e | $Q^{prk}$ | $F_m^{prk}$ | $Q^{lv}$ | $F_m^{mlk}$ | $I_{rr}^{fv}$ | $I_{rr}^{fv}$ | $I_{rr}^{fv}$ | $Q^{lv}$ | $\kappa$ | $\kappa$ | $B_v^{fv}$ | $Q^{rc}$ | $I_{rr}^{fv}$ | $\kappa$ | SF |
| | | 3e | $I_{rr}^{fv}$ | $Q^{mlk}$ | $I_{rr}^{fv}$ | $Q^{lv}$ | $Q^{prk}$ | $Kd_s$ | $\eta_{Rn}$ | $I_{rr}^{fv}$ | $T_w^{lv}$ | $Kd_{sed}$ | $Q^{fv}$ | $B_v^{rc}$ | $Kd_s$ | $Q^{fv}$ | $Q^{rc}$ |
| Spain | Adults | 1e | $B_v^{veg}$ | $F_m^{prk}$ | $Q^b$ | $I_{rr}$ | | $Q^{wtr}$ | $Kd_s$ | $I_{rr}$ | $I_{rr}$ | $I_{rr}$ | $Q^b$ | $I_{rr}$ | | $Kd_s$ | |
| | | 2e | $I_{rr}$ | $Kd_s$ | $I_{rr}$ | $Q^{leg}$ | | $I_F^{frt}$ | | $Q^{leg}$ | $Q^{leg}$ | $Q^{leg}$ | $Q^{fsh}$ | $Q^b$ | | $Q^{fsh}$ | |
| | | 3e | $Q^c$ | | $Q^{leg}$ | $Q^{wtr}$ | | $Q^{leg}$ | | $Q^b$ | $Q^b$ | | | $Q^{leg}$ | | $Q^{wtr}$ | |
| Germany | Adults | 1e | $B_v$ | $Q^{wtr}$ | $Q^{wtr}$ | $Q^{wtr}$ | $B_v$ | $Q^{wtr}$ | $Q^{wtr}$ | $Q^{wtr}$ | $Q^{wtr}$ | $Q^{wtr}$ | | | | | |
| | | 2e | $Q^{mlk}$ | $C_f^{fsh}$ | $B_v$ | $Q^{mlk}$ | $Q^{wtr}$ | $I_{rr}$ | Mig | | | | | | | | |
| | | 3e | $Q^{wtr}$ | $Q^{fsh}$ | $I_{rr}$ | $B_v$ | $F_m$ | $B_v$ | R | | | | | | | | |
| Belgium | Adults | 1e | $Kd_s$ | $Kd_s$ | $F_m^{mlk}$ | $Kd_s$ | $Kd_s$ | $Kd_s$ | $Kd_s$ | $Kd_s$ | $Kd_s$ | $Kd_s$ | | | | | |
| | | 2e | $B_v^{pst}$ | $F_m^b$ | $B_v^{lv}$ | $F_m^b$ | $B_v^{pst}$ | $B_v^{pst}$ Po | $B_v^{rc}$ Ac | $I_F^{lv}$ | $I_F^{lv}$ | $I_F^{lv}$ | | | | | |
| | | 3e | $I_{rr}^{pst}$ | $B_v^{pst}$ | $I_{rr}^{lv}$ | $I_{rr}^{pst}$ | $F_m^b$ | $I_{rr}^{pst}$ | $I_F^{lv}$ | $I_F^{fv}$ | $I_F^{fv}$ | $I_F^{fv}$ | | | | | |
| Sweden | Adults | 1e | $Kd_s$ | $B_v^{rc}$ | $B_v^{rc}$ | $B_v^{rc}$ | $I_{rr}$ | $I_{rr}^{\#}$ | $I_{rr}^{\#}$ | $Y^{lv}$ | $Y^{lv}$ | $Y^{lv}$ | | | | | |
| | | 2e | $I_{rr}$ | $I_{rr}$ | $I_{rr}$ | $I_{rr}$ | $B_v^{rc}$ | $Y^{lv}$ | $Y^{lv}$ | $I_{rr}^{\#}$ | $I_{rr}^{\#}$ | $Q^{wtr}$ | | | | | |
| | | 3e | $I_{rr}^{\#}$ | $Q^{wtr}$ | $Kd_s$ | $B_v^{lv}$ | $B_v^{lv}$ | $Q^{wtr}$ | $Q^{wtr}$ | $Q^{wtr}$ | $Q^{wtr}$ | $I_{rr}^{\#}$ | | | | | |

# Generic model provides acceptable agreement with site-specific model




** Normalized exposure to adults for the well scenario*

# Some general conclusions from BioMoSA (1/2)

- Drinking water dominating
- In general, little differences between sites
- Uncertainty
  - Ratio 95/5 percentile around a factor of 10
- Some parameters need reconsideration
  - Cl-36, Se-79, I-129
    - Root uptake
    - Migration
    - Transfer to milk and meat
    - Parameters partly conflicting
- Calculations with generic model were in the same line as site-specific models results

# Some general conclusions from BioMoSA (2/2)

- Generic model provides acceptable agreement with site-specific model
- Larger uncertainties for releases to
  - Lakes
  - Marine
  - Deep soil
- Transfer is more complex
  - More site-specific
  - More difficult to generalize
  - Poor data