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Analysis of the Fukushima Source Term: Implications for Source Term Estimation from Radiological Observations during Emergencies

Analysis of the Fukushima source term: Scope and objectives

- Reconstruction of fission product (FP) releases from measured local dose rate on-site Fukushima Daiichi NPP or nearby
- Results used for comparison of radiological evidence with results of severe accident analyses for Fukushima Daiichi NPP Units 1 to 3
- Analyses have been performed within OECD/NEA Project BSAF, Phase II: "Benchmark Study of the Accident at the Fukushima Daiichi Nuclear Power Plant“

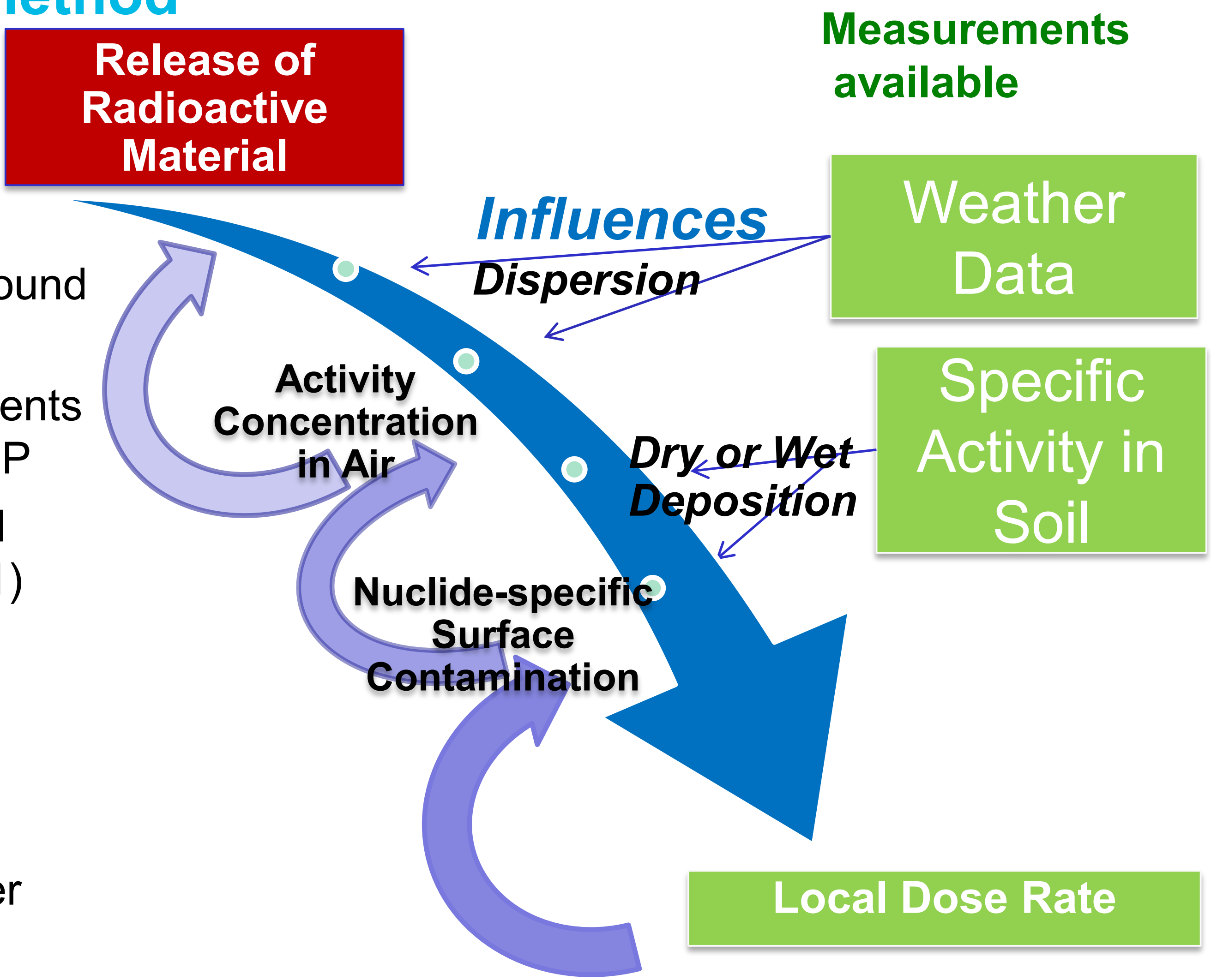
Additional objective by this presentation

- Draw some conclusions potentially useful for source term (ST) assessment during emergencies and further development of corresponding tools

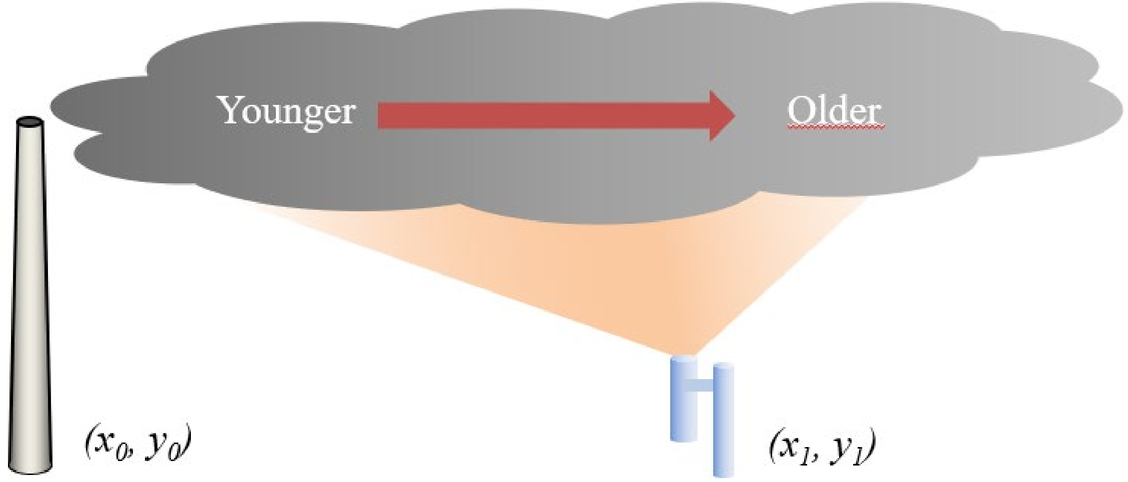
Processes that lead to an observed local dose rate / reconstruction method

Data

- Numerous local dose rate measurements on-site and around Fukushima Daiichi NPP
- Wind, precipitation measurements on-site and 5 km WSW of NPP
- Few soil samples of deposited nuclides (from March 21, 2011)
- No measurements of air concentration during release phases
- No measured source term
- No nearby measurements over ocean



Reconstruction of releases from local dose rate: Basic principle



- Spatial structure of cloud "seen" by monitoring instrument is result of past emissions, dispersion and decay (simplified formula for one nuclide, neglecting decay)

$$h_k = \sum_{j=1}^{k} \chi_{k,j} q_j$$

Cloud shine at monitor point at time t_k

Dispersion of emission from time t_j to monitor point location at time t_k

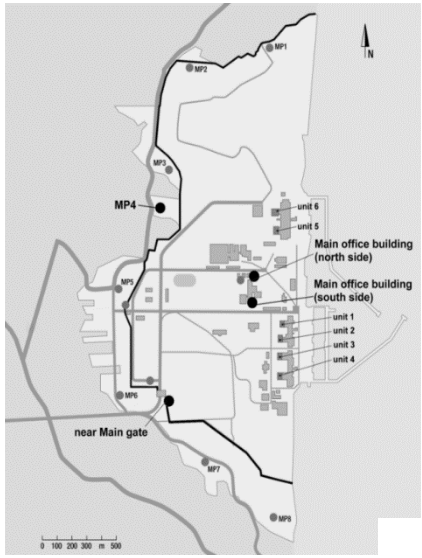
Emission at time t_j

Reconstruction of basic nuclide composition: Specific soil activity samples

Aerosols:

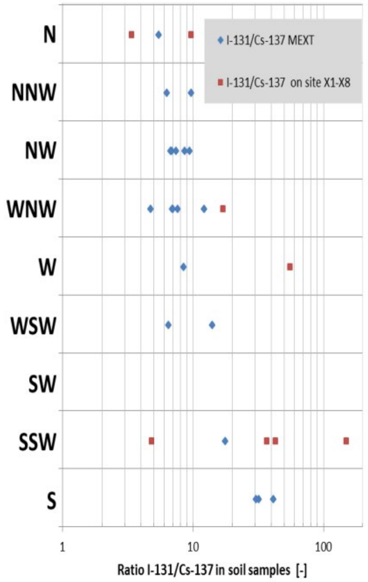
Synthetic soil sample from 8 samples on site between March 21 and March 25, 2011, decay corrected to March 21, 00:00 JST

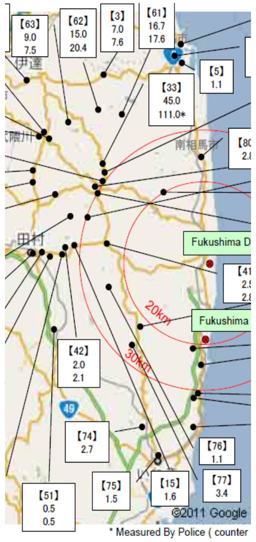
Nuclide	Average Specific Soil Activity [Bq/kg]	Average ratio to Cs-137, +/- RMSE
Nb-95	3.1E+03	0.005 +/- 0.002
Mo-99	1.0E+05	0.16 +/- 0.007
Ru-106	6.9E+04	0.11 +/- 0.032
Ag-110m	6.4E+03	0.010 +/- 0.009
Te-129m	5.5E+05	0.85 +/- 0.26
Te-132	1.4E+06	2.2 +/- 0.7
Cs-134	6.4E+05	1.0 +/- 0.2
Cs-136	1.0E+05	0.16 +/- 0.05
Cs-137	6.5E+05	1
Ba-140	3.5E+04	0.05 +/- 0.03
La-140	1.1E+05	0.17 +/- 0.09



Iodine:

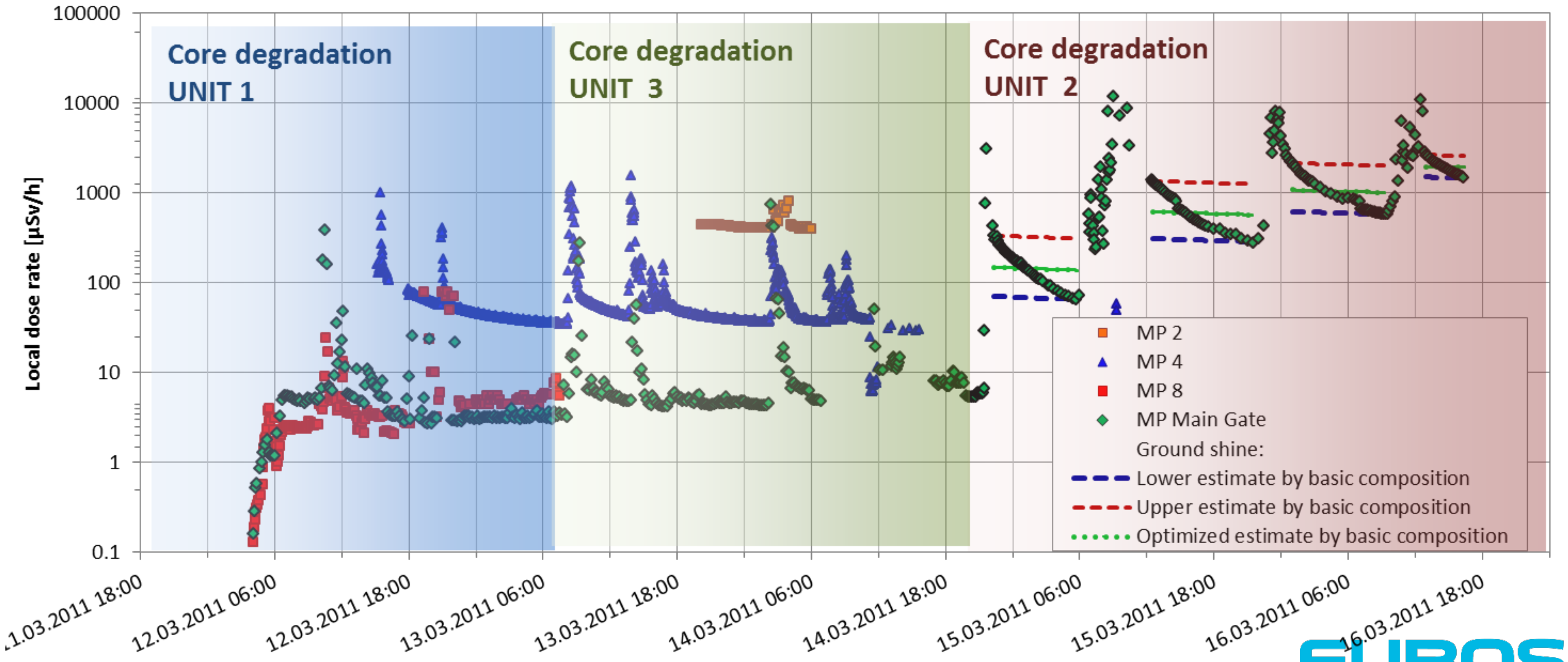
- Large variation of ratios I-131/ Cs-137 on site
- Supplementary analysis at 20 MEXT sampling points
- **Average ratio I-131/Cs-137** (decay-corrected to March 21):
  - **8:1 for wet deposition (N to WSW directions)**
  - **30:1 for dry deposition (SSW to S directions**)
- I-133 and I-135: not measured, ratios to I-131 assumed proportional to inventory ratios
- **I-132: Equilibrium with Te-132 in measured soil samples**





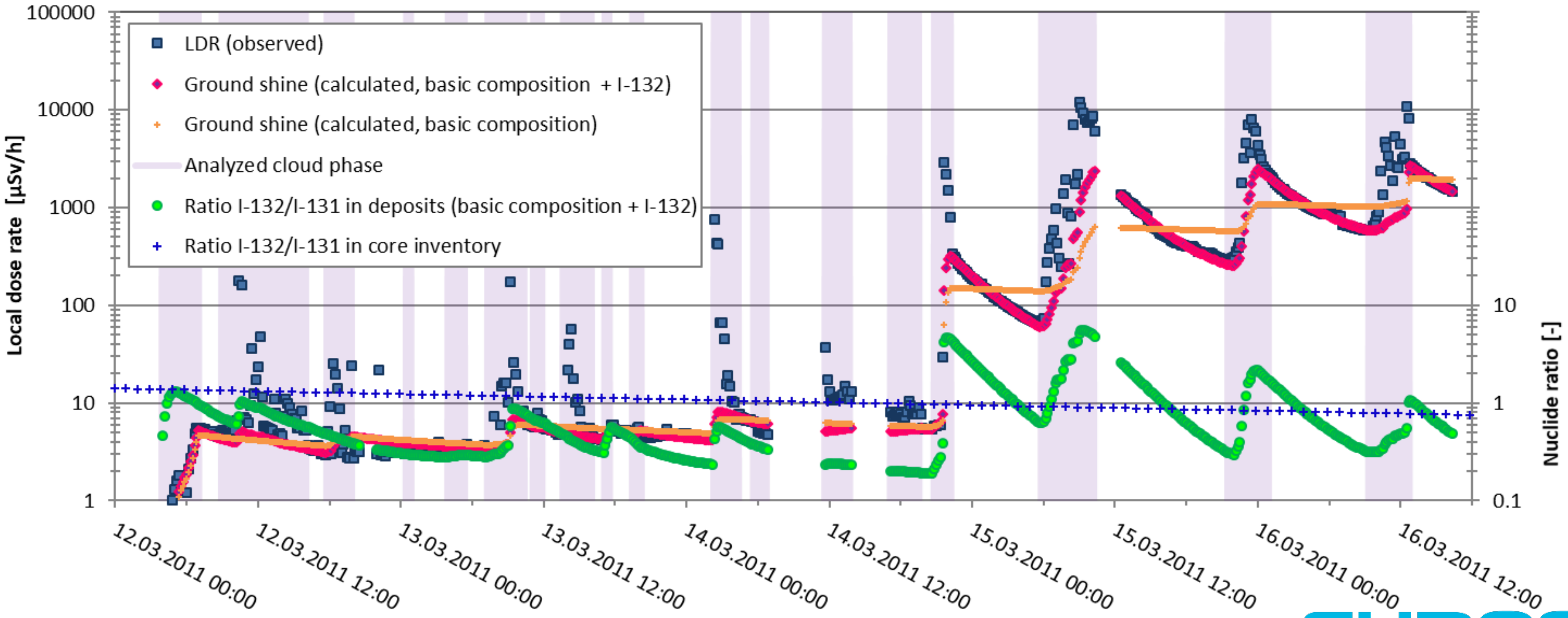
Observed local dose rates (LDR) on-site Fukushima Daichi

- Severe core degradation phases in Units 1 – 3 can be related to measured “peaks”
- Not every “peak” has been linked to events in the plant yet
- Continuous decrease phases after peaks are dominated by ground shine and radioactive decay (Result of in-depth analysis of temporal behaviour)
- “Basic composition” decays too slowly to explain observed decrease in these phases especially after four large peaks at MP “Main Gate”: Unit 2, 14.03. - 16.03.

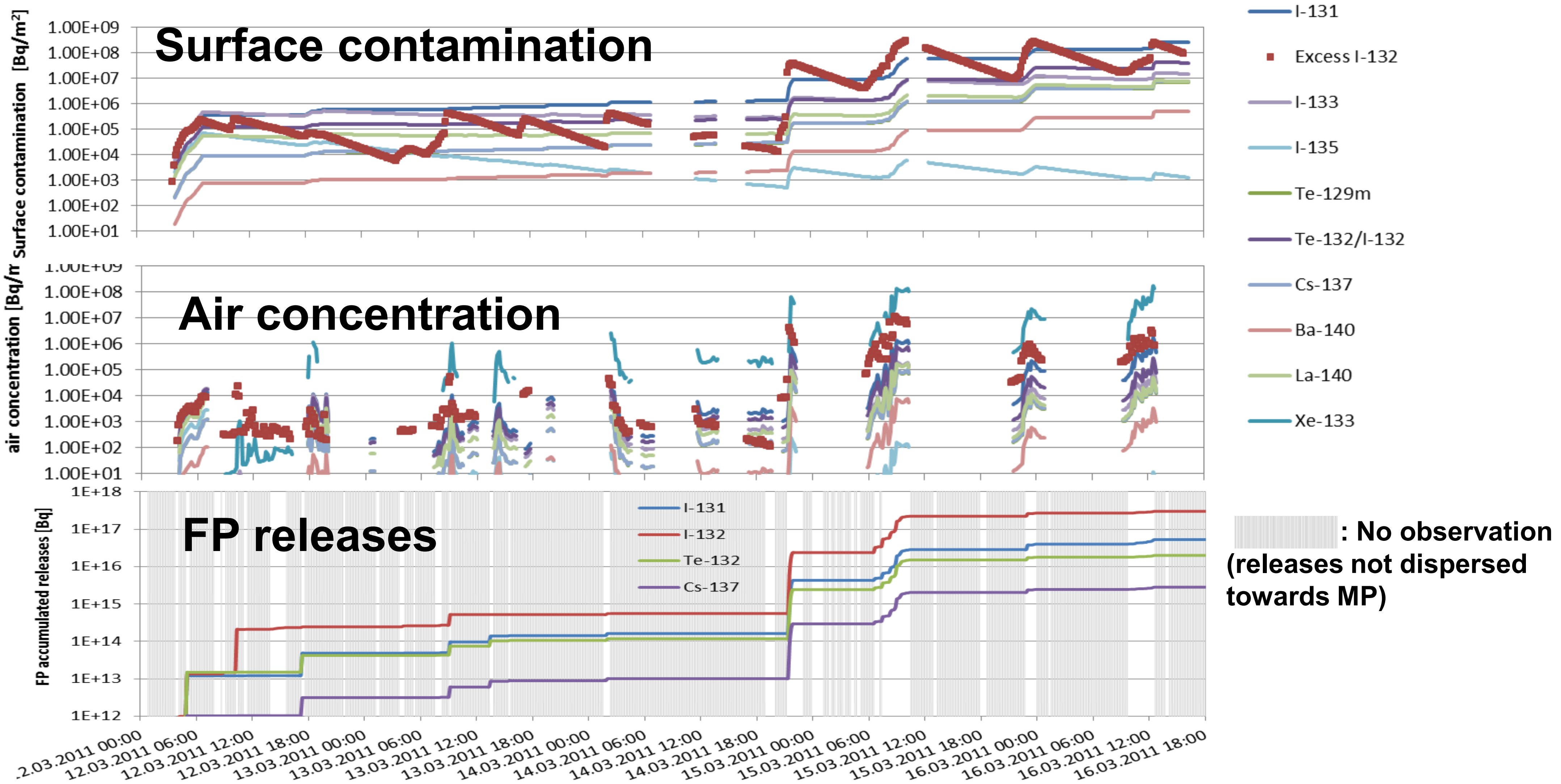


Calculation of ground shine and cloud shine at MP “Main Gate“

- Consideration of contributions by I-132 significantly improves agreement with measurements
- I-132 not in equilibrium with Te-132 in modelled deposits
  - Measurements of air concentration at JAEA Tokai (~120 km south) corroborate I-132 excess
- Partly explainable by excess release of I-132 produced by Te-132 decay in cores
  - Higher Release fraction for Iodine than for Tellurium
  - Calculated ratio I-132 : I -131 in agreement with core inventory before 14.03. 21:00
  - Significant excess of this ratio on 14.03. and 15.03. (additional production process?)



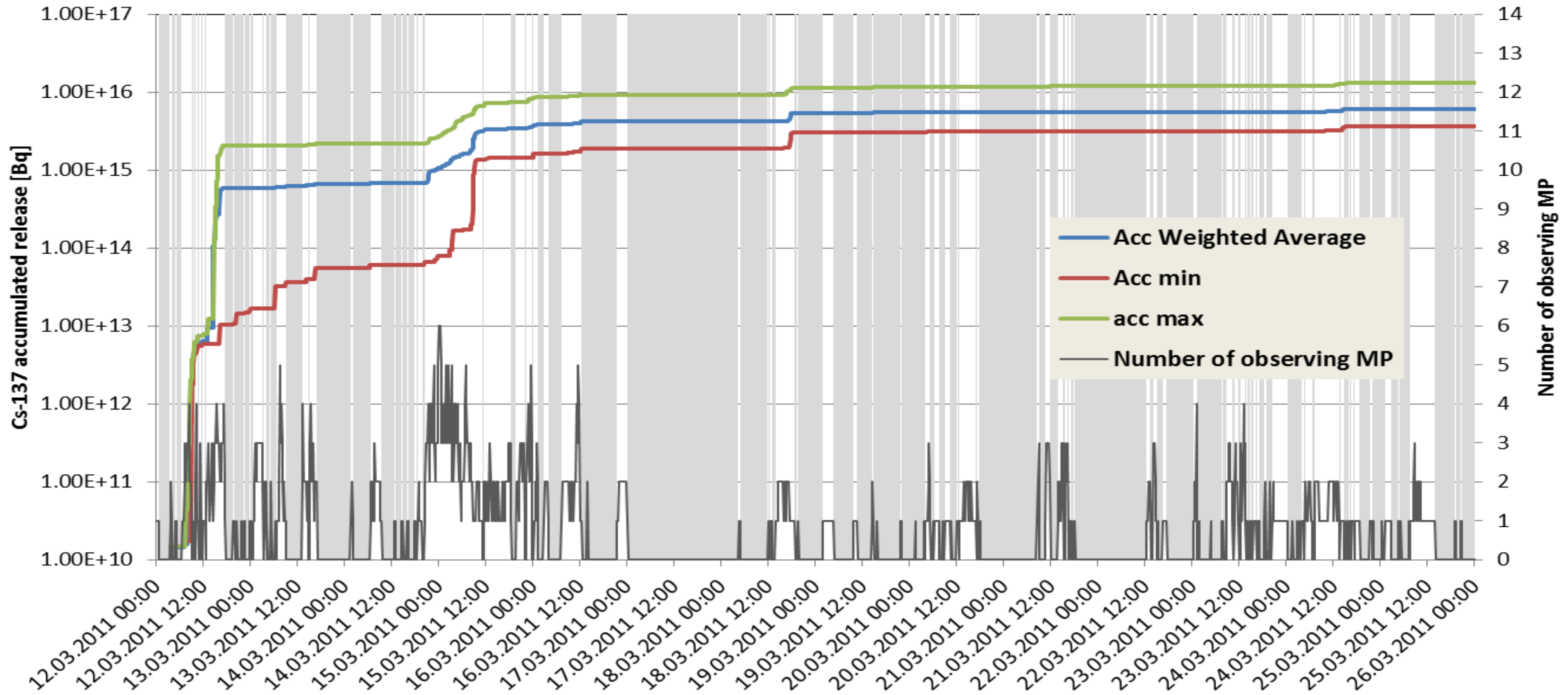
Reconstruction at MP „Main Gate“ including I-132 contributions

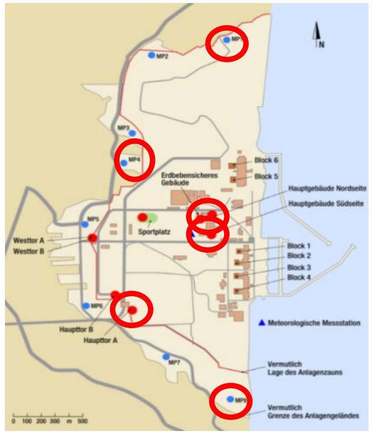


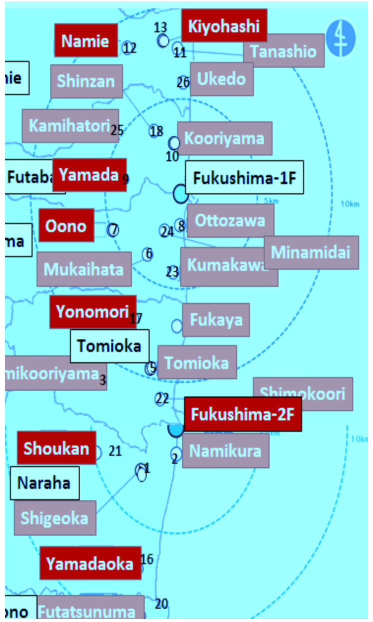
- Overestimation of other FP releases by a factor of 3 if I-132 is not considered!

Reconstruction of FP releases from 14 MP (local dose rate)

- Reconstruction of source term (ST) from local dose rate (LDR) from an ensemble of measuring points –
  - Convergence between lower and upper reconstruction estimates from individual observation points

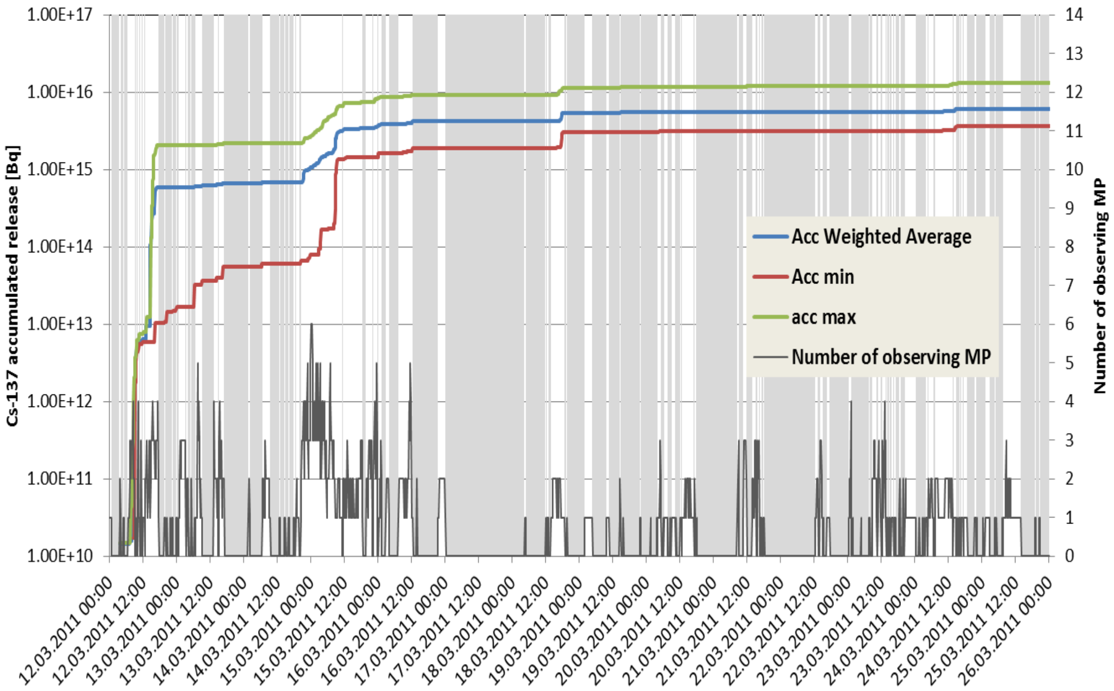






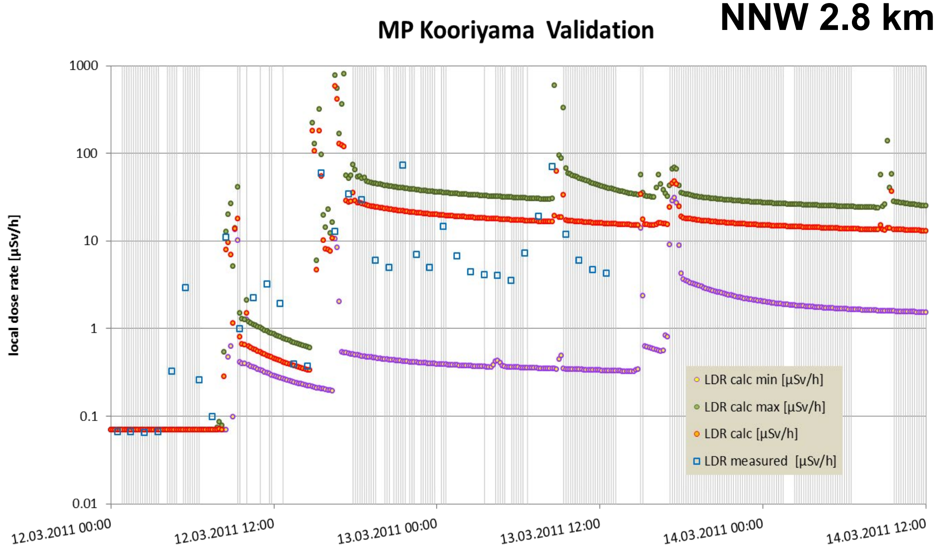
Validation: Method

- **Forward calculation of LDR with given model approach and weather data**
  - For lower ST estimate
  - For weighted ensemble average of ST estimates
  - For upper ST estimate
- **Comparison with observed LDR**
- **Interpretation of deviations**
  - Calculated source term
  - Calculated dispersion
- *Limitations:*
  - Record length of included stations
  - Independent only in measured LDR, but not in weather, dispersion model or nuclide composition
  - No independent data for comparison available

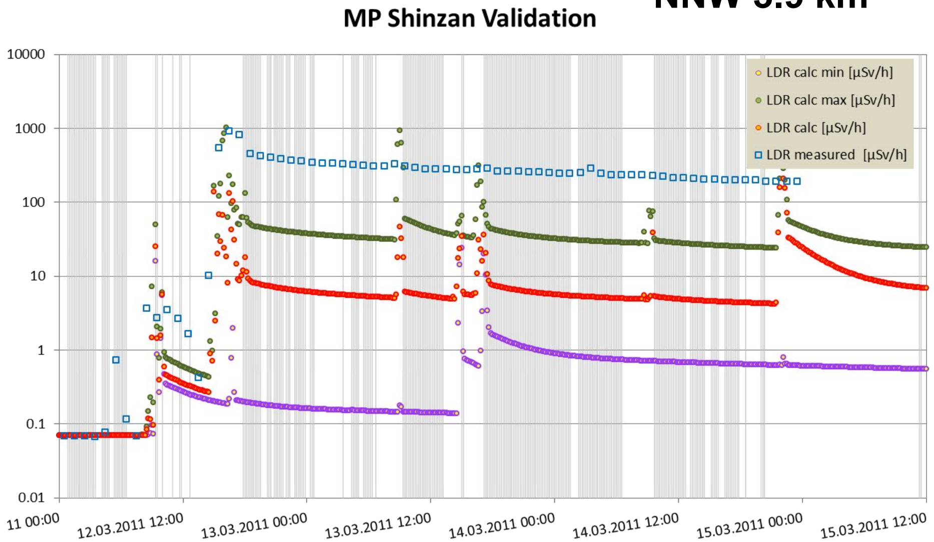


Validation results (1)

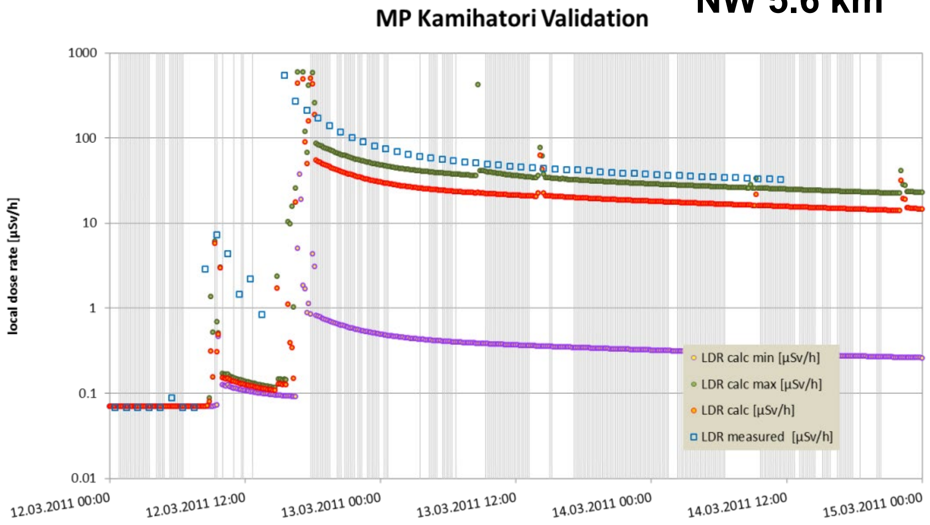
NNW 2.8 km



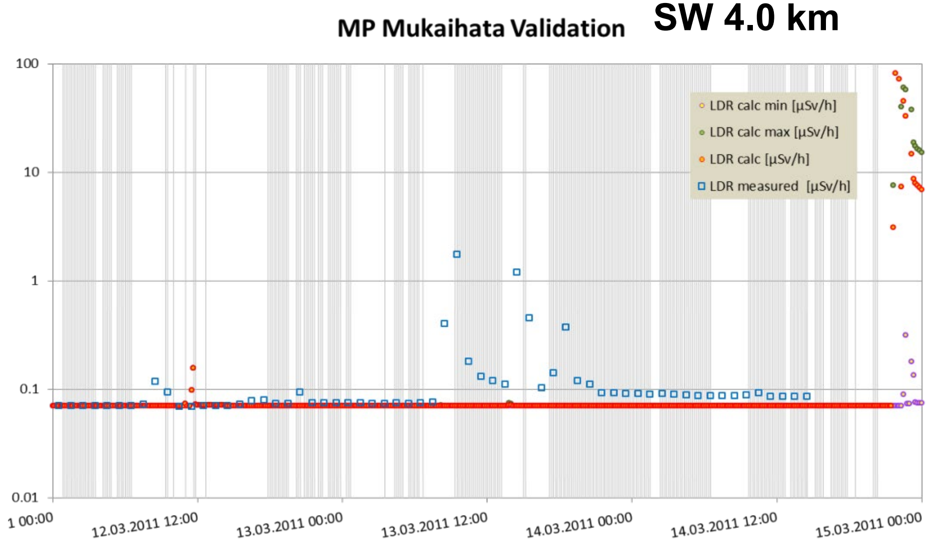
NNW 3.9 km



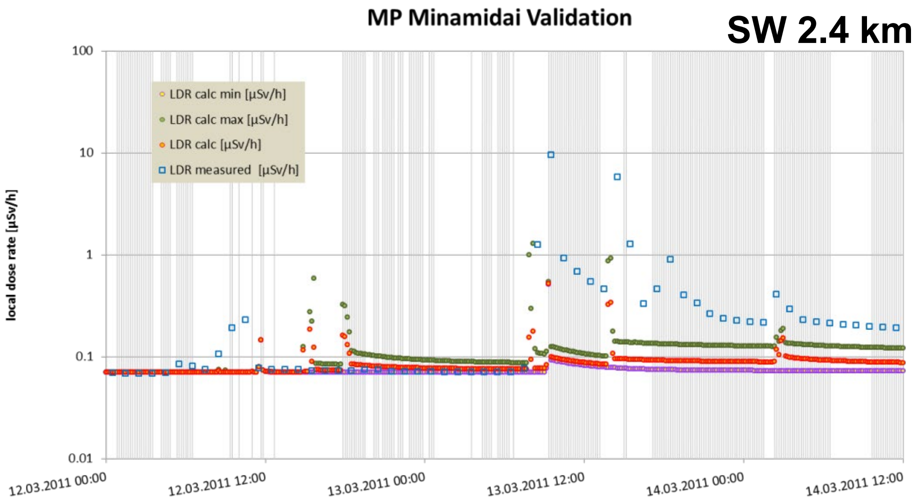
NW 5.6 km

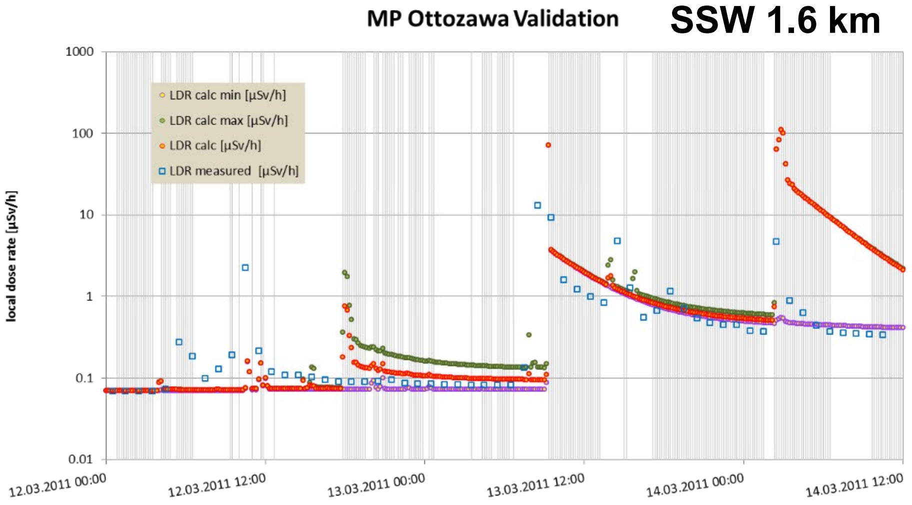


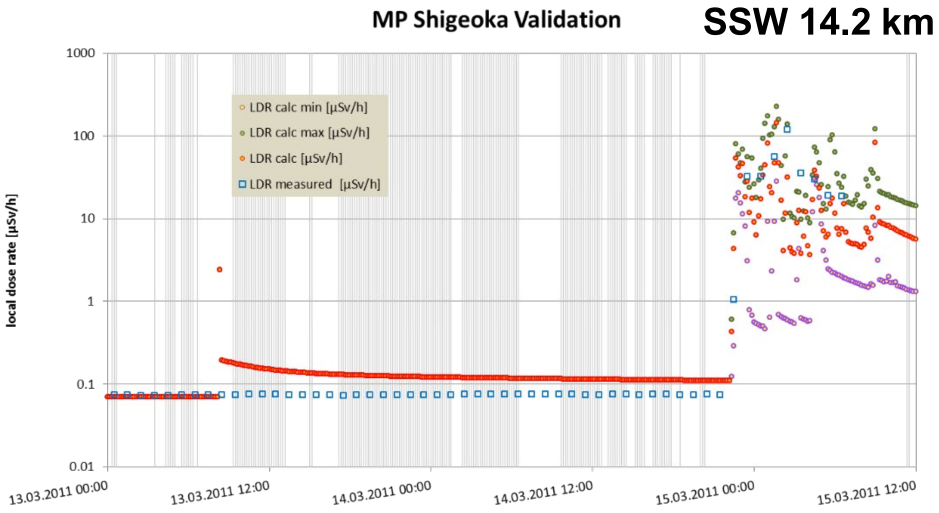
SW 4.0 km

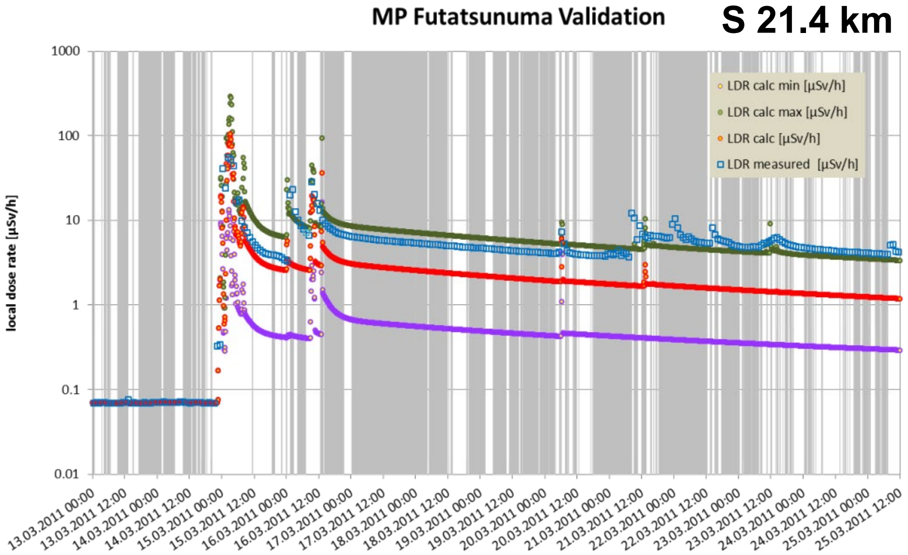


Validation results (2)









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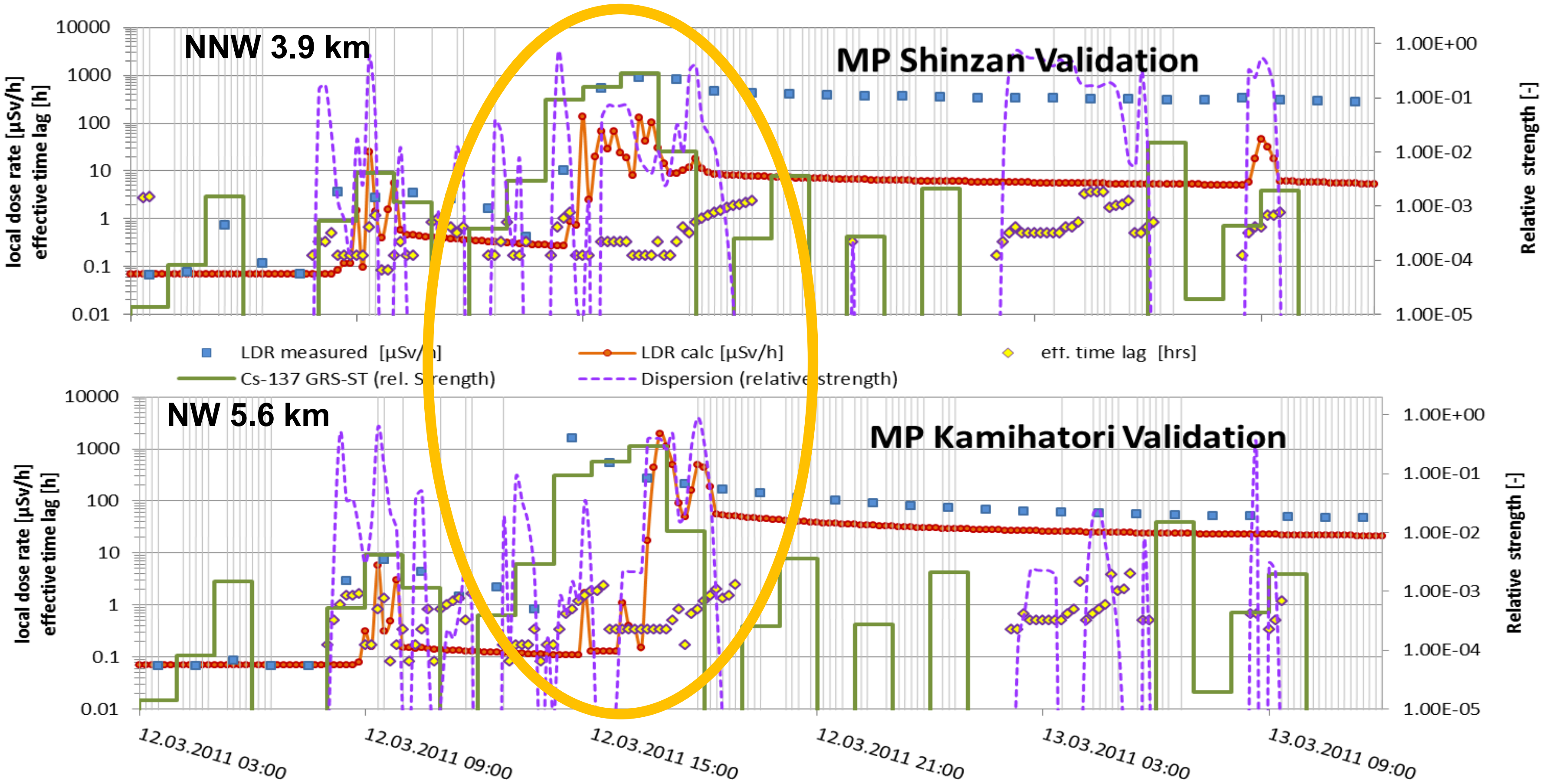
Interpretation of Validation results: Example

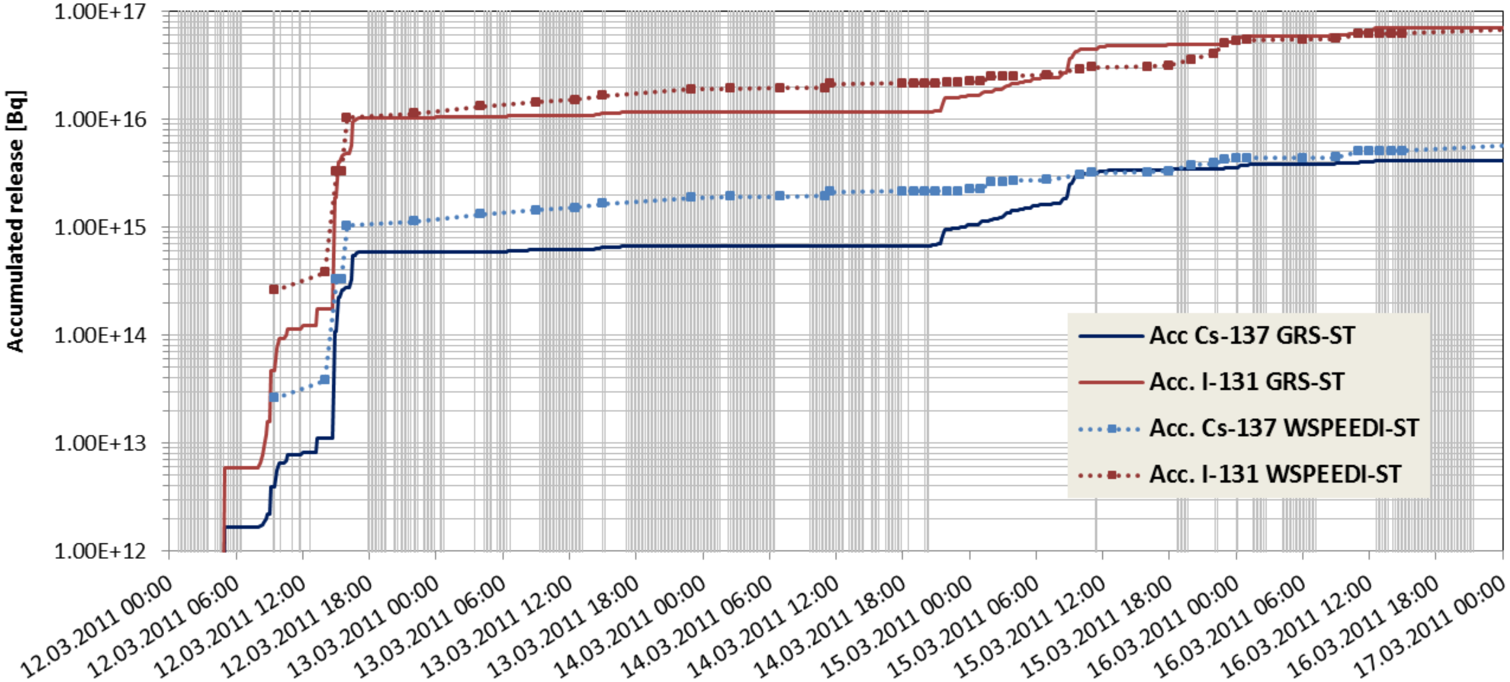


- Qualitative agreement for both MP (as for most MP in the validation set)
- Delicate timing between release and dispersion: Relevant for quantitative agreement

Reconstruction of FP releases from 14 MP (local dose rate)

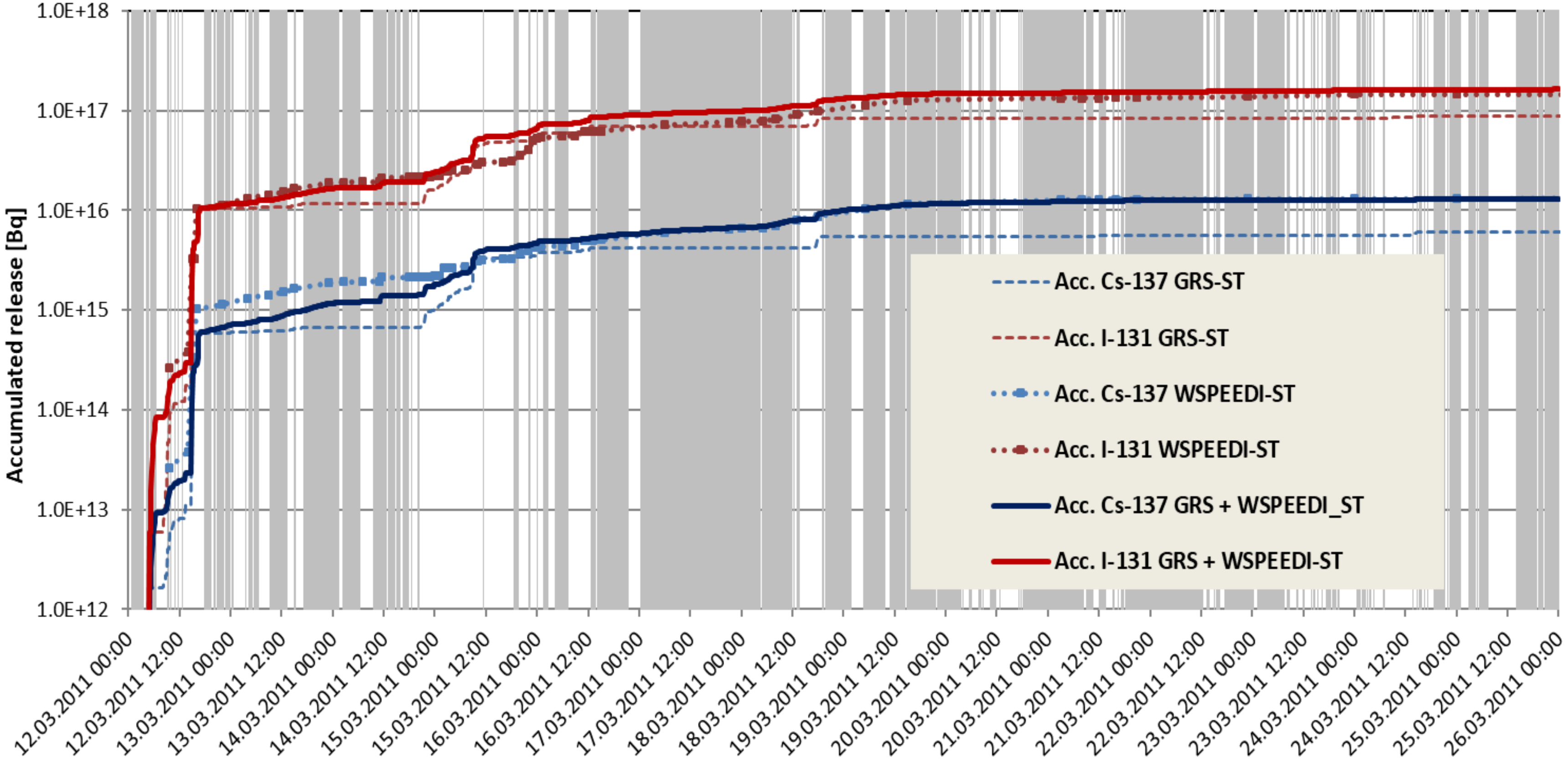
Comparison to reconstruction with Japanese WSPEEDI system*

- Strikingly good agreement between both methods
- GRS reconstruction:
  - No data over ocean
  - Higher temporal resolution using MP at site and nearby
  - Independent estimate, no manual corrections on dispersion
- WSPEEDI reconstruction
  - Whole observational period is covered
  - Larger uncertainties (distant MP, ocean data)
  - Plant data used for release phase determination, manual corrections on dispersion



*Katata et al, 2015: Detailed source term estimation of the atmospheric release for the Fukushima Daiichi Nuclear Power Station accident by coupling simulations of an atmospheric dispersion model with an improved deposition scheme and oceanic dispersion model. *Atmos. Chem. Phys.*, **15**, 1029–1070, doi:10.5194/acp-15-1029-2015.

Combination of GRS and WSPEEDI ST reconstruction results



- GRS data gaps filled by WSPEEDI data
- Combination of advantages from both methods
- Database for comparison with ST calculations by severe accident analysis codes

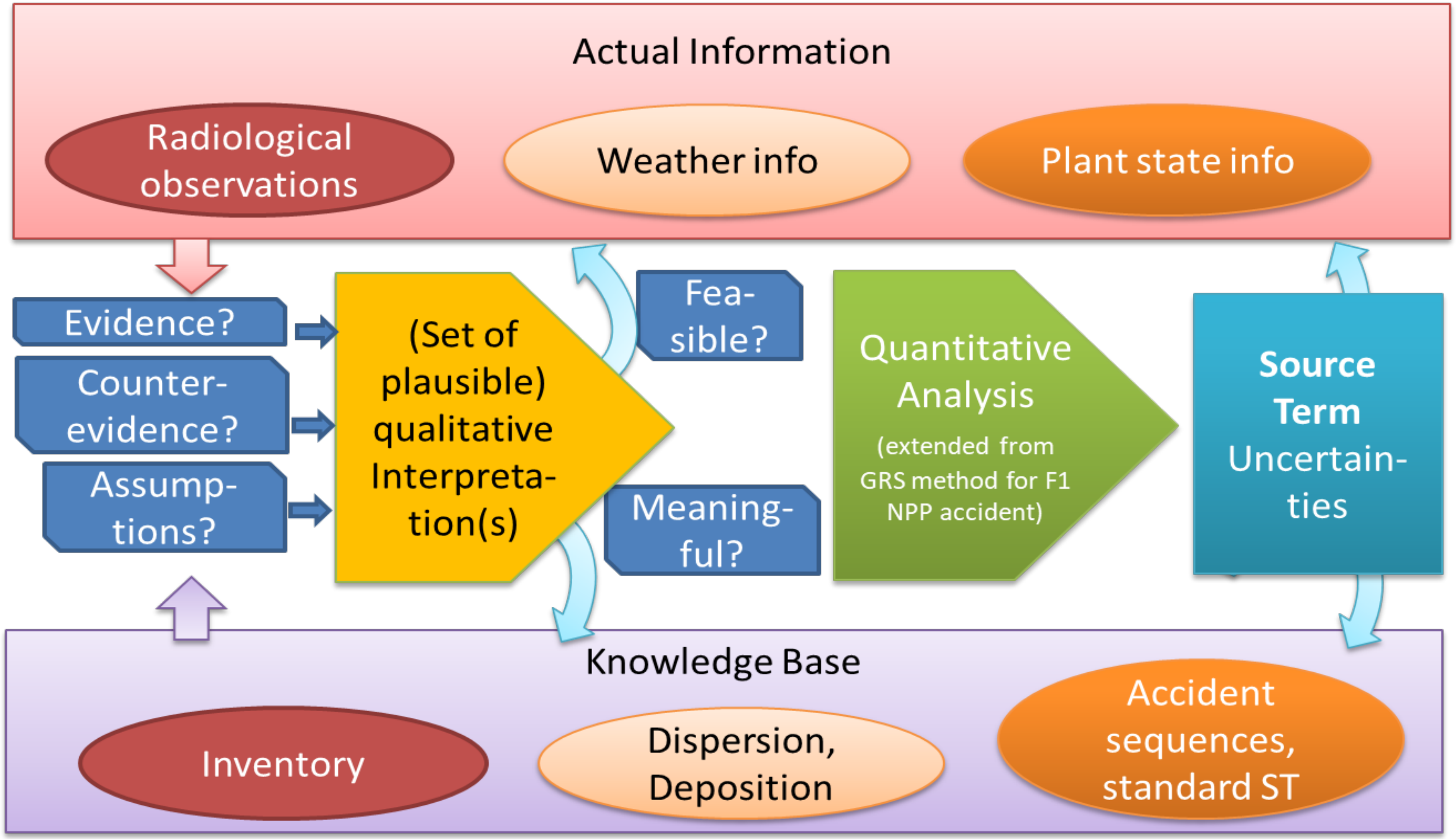
Incorporation into „low end“ ST assessment tool for emergencies (1)

Profile

- Combine plant or source data (if available) with radiological data on-site or nearby (up to about a dozen kilometres)
- Work on a levels as simple as possible
  - Independent from plant information if the latter is not available
  - Deal with sparse, incomplete or even contradicting data
  - Run on standard PC or notebook without special software requirements
  - Interfaces for automatic or manual data transfer
  - Enable qualitative or quantitative conclusions
    - according to availability of information
  - Provide easy-to-understand explanation of uncertainties / ambiguities
- Enhance level of sophistication if suitable information is available

Incorporation into „low end“ ST assessment tool for emergencies (2)

Working scheme



Conclusions

- **Observed local dose rate during first days of Fukushima accident:**
  - Contribution of I-132 exceeding equilibrium with mother nuclide Te-132 especially at on-site measuring points (MP)
  - Consideration essential for use of these MP in ST reconstruction
- **Origin of additional I-132 (and possibly other short-lived nuclides):**
  - Excess release of I-132 produced by Te-132 decay in damaged cores (higher release fraction for Iodine than for Tellurium)
  - Additional production process for two large peaks on 14.03. and 15.03 likely (coincidence with core degradation in Unit 2, recriticality?)
- **Relevance for ST assessment and emergency management:**
  - Effect of short-lived nuclides should be included in source term and inhalation dose estimates based on local dose rate measured nearby accident site
  - Method presented currently being incorporated into an assessment tool

Thank you for your attention!