Assessment of possible consequences from severe accidents at nuclear power plants in Europe

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# The flexRISK project

- > 2009-2012, interdisciplinary
- Main goals:
  - Demonstrate the overall geographical distribution of the risk caused by severe accidents in nuclear power plants in Europe
  - Show the contribution of different nuclear power plants according to type and geographical location
  - Study the effects of phase-out scenarios
- Methods:
  - Collect data for all 228 NPPs in Europe + Akkuyu (TR), Bushehr (Iran)
  - Identify severe accident with inventories, release fractions, release frequencies for each plant
  - Perform Europe-wide dispersion & dose calculations for 2788 cases

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 Produce single-case maps and various aggregated risk parameters

#### Accident data

- Limited data available (nuclear industry business secrets)
- Grouping of NPPs into similar types
  - ▶ 13 groups for release shapes (duration and effective height)
  - 24 groups for release fractions (of inventory being released)
  - Where available (public), plant-specific data used
- Different types of severe accidents considered, e.g.
  - Steam generator tube ruptures (late)
  - Core melt accident with failure of containment isolation (early)

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- Interfacing Systems Loss-Of-Coolant Accident (early)
- Core power excursion RBMK (early)
- Loss of carbon dioxide coolant GCR (late)

# Release fractions & accident frequency



- Most accidents considered release 10-30% of inventory of volatile nuclides, some up to ca. 60%
- Frequencies span 5 orders of magnitude!

### Dispersion calculations



- ► Lagrangian dispersion model FLEXPART, dry and wet depo
- Fine output domain 10 km (red), Coarse output domain 1 deg (orange), Calculation domain (yellow)
- ERA-Interim 70 km meteo input data for 1995, 2000-2009, 3-hourly, 2788 cases (real weather situations)
- 2 weeks in VSC-2 Vienna supercomputer, 2.5 TB compressed output

#### Ground contamination & concentration examples



1.E-00 1.E+01 1.E+02 1.E+03 1.E+04 1.E+06 1.E+06 1.E+07 1.E+08 Bajim2

Belleville-1 Concentration from a 1031.70 PBq release of I-131 ( 30.00%) Simulation start 19951009 07 Actual time 19951009 10



1.0E-02 1.0E-01 1.0E+00 1.0E+01 1.0E+02 1.0E+03 1.0E+04 1.0E+05 1.0E+08 Balm3

Muchleberg-1 Deposition from a 86.50 PBq release of Ce-137 Ion start 19850511 22 Actual time 19850526 22 cu



Krsko-1 Deposition from a 59.04 PBq release of Cs-137 Simulation start 19950425 16 Actual time 19950510 16



Asco-1 Deposition from a 109.01 PBq release of Ca-137 imulation start 19950126 06 Actual time 19950210 06



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### Risk definition and calculation

- Risk is taken as probability of exceeding a threshold contamination or dose
- > Justification: intervention measures only above certain levels
- Emergency preparedness needs to know a (nearly) "worst case", not a mean value
- Thus we need to simulate a large number of cases
- ▶  $P = P_{\text{acc}}(\text{accident happens}) \times P_{\text{met}}(\text{gridpoint affected})$ 
  - P<sub>met</sub> is the meteorological risk, determined by transport and deposition properties of the atmosphere in combination with release shape (duration and height of release)

### Risk maps examples

Philippsburg-2 [Weather-related] Probability of thyroid dose infant 07 d > 10.00 mSv Maximum in AT 5.13 %



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1.0E-04 3.2E-04 1.0E-03 3.2E-03 1.0E-02 3.2E-02 1.0E-01 3.2E-01 1.0E+00

Intervention level for iodine prophylaxis of children in Austria (10 mSv 7 day inhalation dose): weather-related probability of exceeding the intervention level for Philippsburg 2





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1.0E-11 1.0E-10 1.0E-09 1.0E-08 1.0E-07 1.0E-06 1.0E-05 1.0E-04 1.0E-03

Distribution of total risk: Probability of exceeding the 37 kBq/m2 Cs-137 IAEA threshold for all active NPPs (met. frequency x frequency of accident in each NPP unit)

### Risk originators for Austria

 Contribution of each NPP country to Austria's risk of receiving a contamination over 1480 kBq/m2 on the part of the country indicated in the box-and-whisker



► Risk for Austria is dominated by Czech NPPs

# Application of flexRISK methodology to Lubiatowo case

- Possible off-site consequences for three reactor designs (*Hitachi ABWR*, *Areva EPR*, *Westinghouse AP1000*) proposed for new Polish NPP were examined
- For each design, two accident sequences were assumed, with intact and bypassed containment respectively
- Dispersion of releases resulting from each sequence were simulated using Flexpart
  - revised wet deposition scheme with more complex parametrization: in cloud and below cloud scavenging
  - ▶ 86 real meteorological conditions from 1995 (overall 516 simulations), output on grid 3 × 3 km
- Evaluated radiological quantities were: time integrated deposition (Bq/m<sup>2</sup>), time integrated concentration (Bq s/m<sup>3</sup>) and various types of doses for infants and adults (mSv)
- Expected doses and countermeasures for selected scenarios were evaluated in Gdańsk, Gdynia and Warsaw respectively

# Application of flexRISK methodology to Lubiatowo case

- Variability of meteorological condition
  - Trajectory of the plume and intensity of deposition are governed by prevailing meteorological conditions
  - Three contamination patterns for the same source term and different meteorological conditions:



 Various meteorological conditions can results in complicated contamination patterns and severe contamination of Polish territory or territories of other countries

### Application of flexRISK methodology to Lubiatowo case

- Results show that under adverse meteorological conditions, severe consequences are likely far beyond emergency planning zone for all three reactor designs
- Simulations revealed possibility of exceeding intervention limits for iodine prophylaxis all over the Poland and even further. Limits for sheltering and temporary relocation were exceeded in distance range including Gdańsk and Gdynia
- These extreme situations, although unlikely, must be also considered
- The possibility of very large releases, even with extremely small probabilities, leads to correspondingly serious potential consequences
- Comprehensive overview of all cases is available online at http://www.univie.ac.at/theoret-met/flexrisk\_pl/

### Conclusion

- Risk pattern reflects site density, NPP type and climateMaxima: E. Central Europe, parts of FR, around large sites in UA and RUMinima on N European Atlantic coasts and in Mediterranean
- Substantial consequences (intervention measures) possible for distances up to 500-1000 km, more frequent / severe for up to 100-300 km.
  - That's in agreement with Chernobyl experiences, but many didn't want to fully face these consequences
- Emergency planning presently focussing on too small areas. In reality, almost all of Europe should be prepared for nuclear disaster
- Risk distribution depends on level of damage: high damage is more concentrated, lower damage spreads over long distance
- Risk distribution also depends strongly on accident frequency, but this parameter is highly uncertain

#### Extensive project web site

- http://flexrisk.boku.ac.at
- http://www.univie.ac.at/theoret-met/flexrisk\_pl/

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flexRISK	ŕ
Navigation Menu	
Risk export of NPP countries: Probability of exceedance of selected contamination and dose levels aggregated over all cases	
The following three scenarios can illustrate the effects of possible phase-outs for older and riskier units:	
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Read more about the selected contamination levels for Cs-137 and correlated intervention measures	- 1
Also you can view results on a large domain or a scored domain. We reasonmend the scored domain where ever possible, as patement in the large domain are monohed do to the course resulted on (gonor. 100 Mr. Indi S Mr. In the scored domain). Specially, DO INDT LOOK of COAREL DOMAINT ON INDI VALUE (e.g. 1 yr effective does 2 20 mSr). Through the < and > monthe of the sing of the image rouse on horse to other cates and within between the three types of results. If the image does not appear, Idls (Johny) (repeatedly if necessary).	
NPP country Scenario Type of result Domain Map / boxplot / relative risk (Al countries Reactors in operate Probability of 7.d r Zoomed domain (der 10 lm) Maps show	
Risk originating from all countries     Scenario 1: NPPs active 1/2011   Maximum in AT 1.97E-05     Probability of 2 dthyroid does for inlants > 10 mSv	
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