Antonio Guglielmelli – Federico Rocchi

Statistical methodology for the evaluation of the radiological impact over the Italian territory of a severe accident at Krško NPP

Italian National Agency for New Technologies
Energy and Sustainable Economic Development

EUROSAFE 2017

Summary

- Motivations
- Introduction
- Methods
- Tools
- Results
  - Source Term evaluation
  - Statistical analysis
  - Deterministic analysis
  - Forecast alert methodology

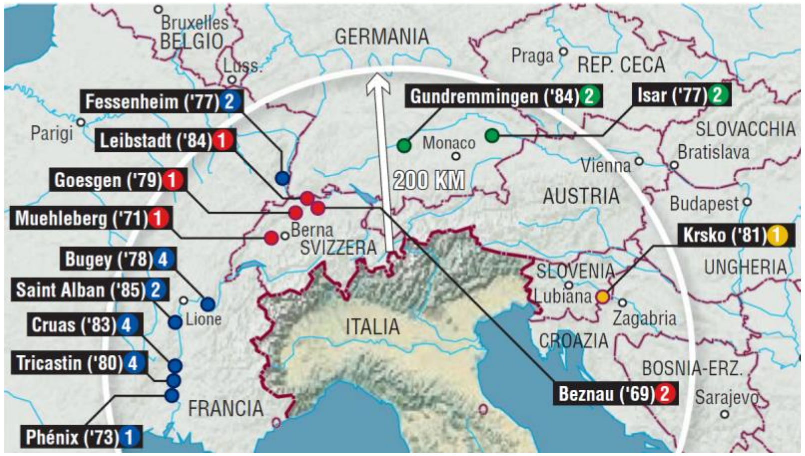
General Motivations

- Situation: Italy is surronded, at less than 200 km from it's borders, by 25 foreign active NPPs;

- Needs: to improve Italian skills, methods and tools in the field of EP&R;

- Aim: to be able to perform «preliminary» assessment of the radiological impact of a severe accident on Italy;

Country	NPPs	Reactor types	Distance from Italian borders
[-]	[-]	[-]	[km]
France	16	PWR	~ 120 – 180
Switzerland	5	PWR - BWR	~ 100 – 130
Germany	4	PWR - BWR	~ 170 – 180
Slovenia	1	PWR	~ 130
TOTAL	26	PWR - BWR	~ 100 – 180



Introduction

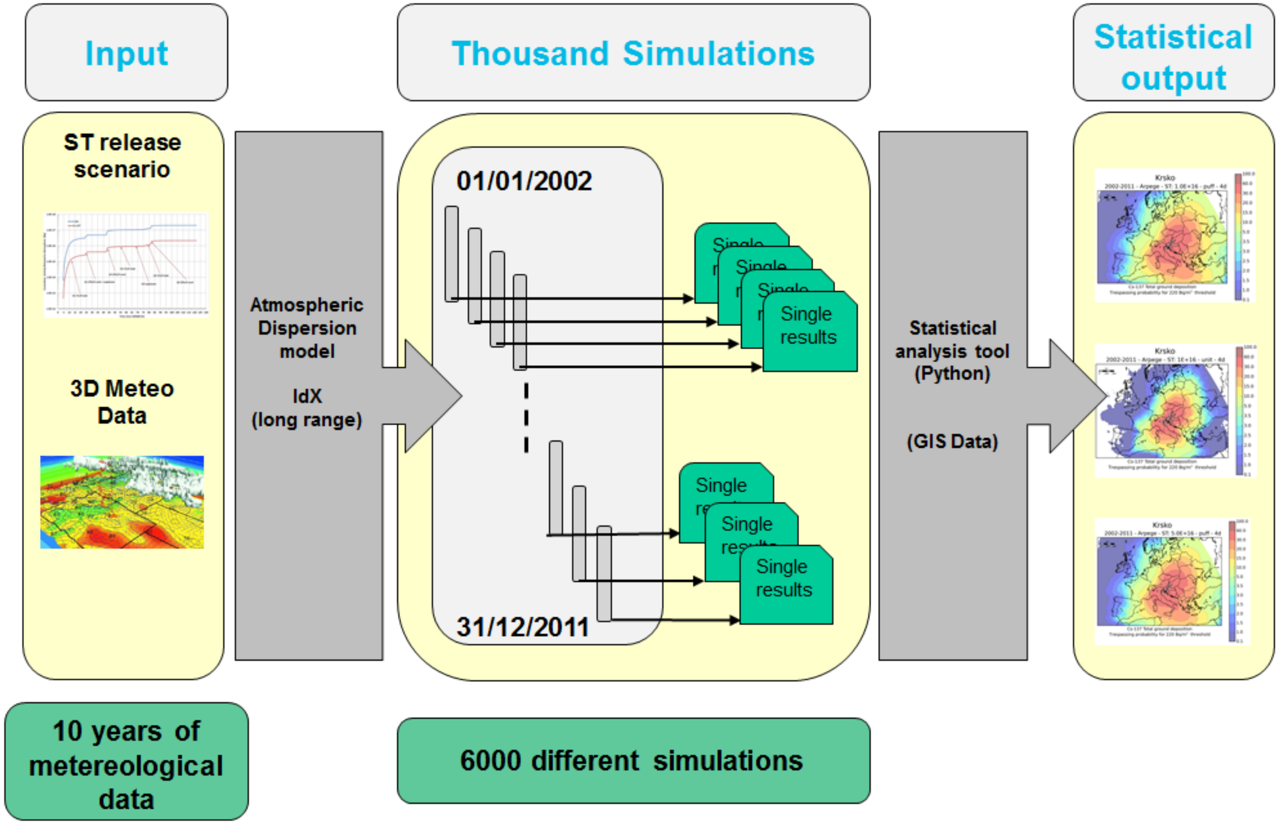
- Krško: is one of the closest NPPs to the Italian territory;
- Krško accident: it would most likely have an impact on Italy;
- Goal: to evaluate the radiological impact on Italy:
  - Methods: Statistical analysis and deterministic study;
  - Tools: French IRSN's and U.S.NRC's codes;
  - Results: Statistical and deterministic maps;
- Alert methodology: Forecast alert methods are also proposed
  - Methods: EURDEP stations network;
  - Tools: RASCAL 4.3 code;
  - Results: Gamma dose-rate values some hours before the event;

Statistical approach – methods

- Statistical method:
  - Several hundred simulations of the same severe accident at different times and weather conditions, using real meteo data;
  - The outcomes are statistically averaged to obtain a threshold trespassing probabilistic distribution map;
  - Statistical methods cannot provide a real-time answer to a severe accident, but are the most powerful tools to give indications for the countermeasures to be taken and long-term recovery phase actions;
  - The quantity evaluated is the trespassing probability map of Cs-137 total ground deposition threshold at the end of simulation;

Statistical approach – methods

- Configuration: make 600 simulations per year, over 10 years of real meteo data (6000 different simulations);

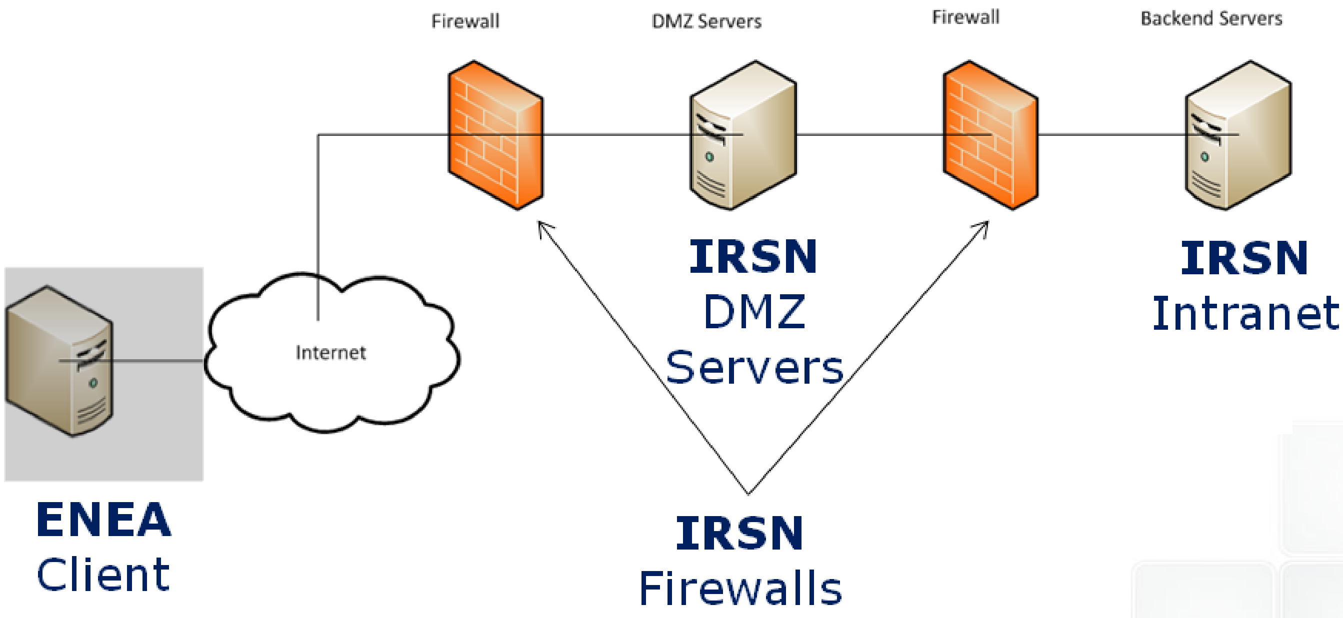


Statistical approach – codes

- IdX: code for atmospheric transport simulations:
  - IdX is a French code developed by the IRSN for which ENEA FSN-SICNUC has signed a bilateral cooperation agreement;
  - IdX is included in IRSN's C3X calculation platform dedicated to evaluate EP&R on a regional scale;
  - The models implemented in IdX have been validated against the European Tracer Experiment (ETEX), the Algeciras release, and the Chernobyl accident;
- consX: code for the assessment of the projected doses;
- Python: language used for output data post-processing.

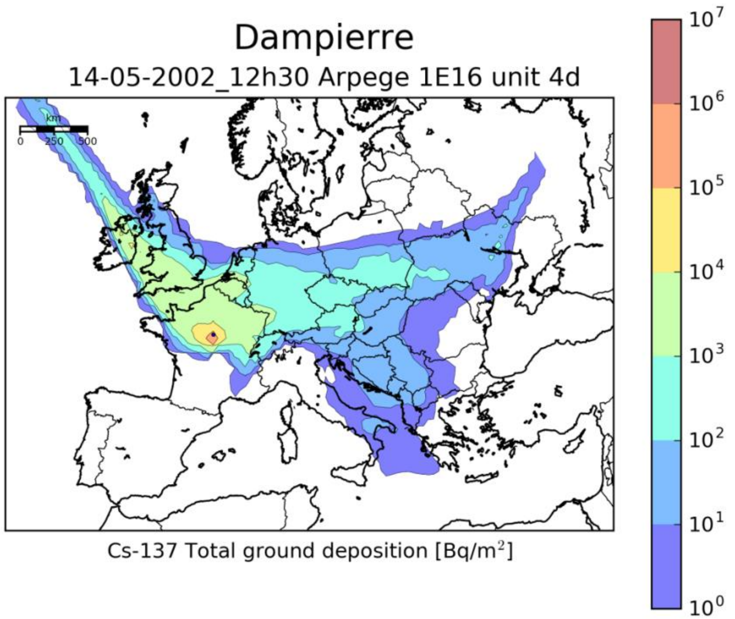
Statistical approach – codes

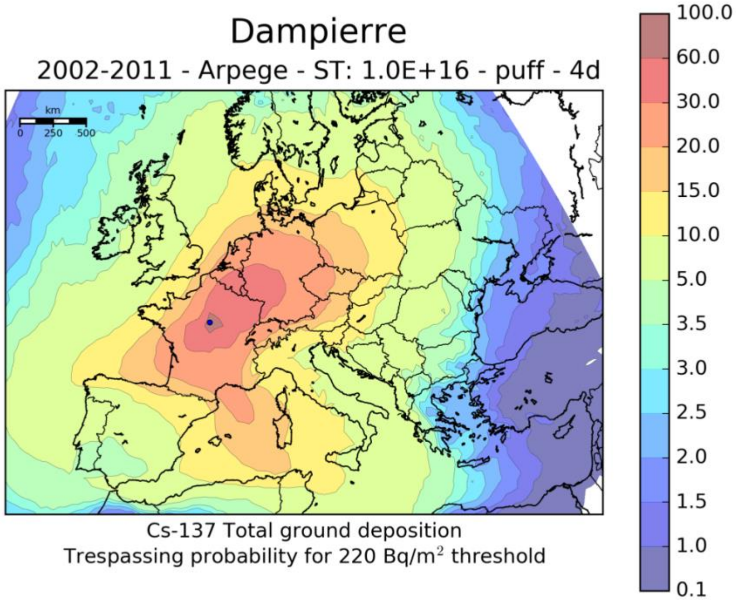
- Hardware: User interface is installed in Bologna (Italy); IdX and consX are resident and run, for security reasons, at IRSN on a DMZ dedicated server.



Statistical approach – codes output

- Single simulation results





- Statistical post-processing results

Statistical approach – parameters

- Metereological data:
  - Meteo France (2002-2011 @ Arpege);
- ST dynamics:
  - Puff (1 hours) and Unit (3 days);
- ST emissions:
  - 5.0E+15, 1.0E+16, 5.0E+16 Bq (only Cs-137);
- Atmospheric transport:
  - Four days (enough to study the impact over Italy);
- Simulations:
  - Two emissions/day, for a total of 6000 simulations.

Arpege @ 50 km

Statistical approach – physical quantities

- IdX results have been used to evaluate, with consX, two radiologically-relevant derived quantities:
  - Total ground deposition [Bq/m^2];
  - Time-integrated air concentration [Bq.s/m^3];
- In a preliminarly phase, the simulations were conducted with only one isotope: ^{137}Cs;
- The contribution of the other isotopes have been evaluated by means of specific ST isotopic ratios information;
- ST isotopic ratios are those evaluated by ENEA for the Fukushima accident;

Statistical approach – threshold limit

- Due to the Krško NPP distance from Italy, the long-term effect of land contamination was used as physical limit;
- The lowest land contamination levels of the Italian legislation are those related to leaf vegetables;
- These levels are used for the evaluation of contamination thresholds;

Isotope	Max. Contamination Level – MCL [Bq/m^2]
^{89}Sr	1.5E+03
^{90}Sr	1.5E+03
^{131}I	4.0E+03
^{134}Cs	2.5E+03
^{137}Cs	2.5E+03
^{239}Pu	1.6E+02

Maximum contamination levels for leaf vegetables

Statistical approach – threshold limit

- The «equivalent» threshold contamination level was imposed with the following expression:

$$\sum_{i=1}^{N} \frac{CL_i}{MCL_i} = 1 \quad \begin{cases} CL_i = initial\ contamination\ level \\ MCL_i = maximum\ contamination\ level \end{cases} \quad X_i = \frac{CL_i}{CL_{137_{Cs}}}$$

- It's possible to reduce the contaminaton threshold to a single-parameter (Xi) expression:

$$\sum_{i=1}^{N} \frac{X_i CL_{137_{Cs}}}{MCL_i} = CL_{137_{Cs}} \sum_{i=1}^{N} \frac{X_i}{MCL_i} = 1 \quad \Longrightarrow \quad CL_{137Cs}\Big|_{lim} = \frac{1}{\sum_{i=1}^{n} \frac{X_i}{MCL_i}}$$

Statistical approach – threshold limit

- The coefficients *Xi* are evaluated assuming that the transport is the same for each isotope, and taking care of decay, as:

$$X_i \cong \frac{ST_i \cdot \beta_i \cdot k_i}{ST_{137_{Cs}} \cdot \beta_{137_{Cs}} \cdot k_{137_{Cs}}} = \frac{ST_i}{ST_{137_{Cs}}} \cdot k_i \quad \begin{cases} \beta_i = \beta_{137_{Cs}} & \text{Same transport} \\ k_{137_{Cs}} = 1 & \text{Long decay time} \end{cases}$$

- Taking into account the decay time for each isotopes, an «equivalent» 137Cs threshold was determined.

Isotope	MCL [Bq/m2]	ST [Bq]	K_i [-]	X_i [-]
^{89}Sr	1.5E+03	4.5E16	1	2.1
^{90}Sr	1.5E+03	3.4E15	1	0.2
^{131}I	4.0E+03	2.0E17	0.71	6.8
^{134}Cs	2.5E+03	3.1E16	1	1.5
^{137}Cs	2.5E+03	2.1E16	1	1.0

Statistical approach – physical limits data & results

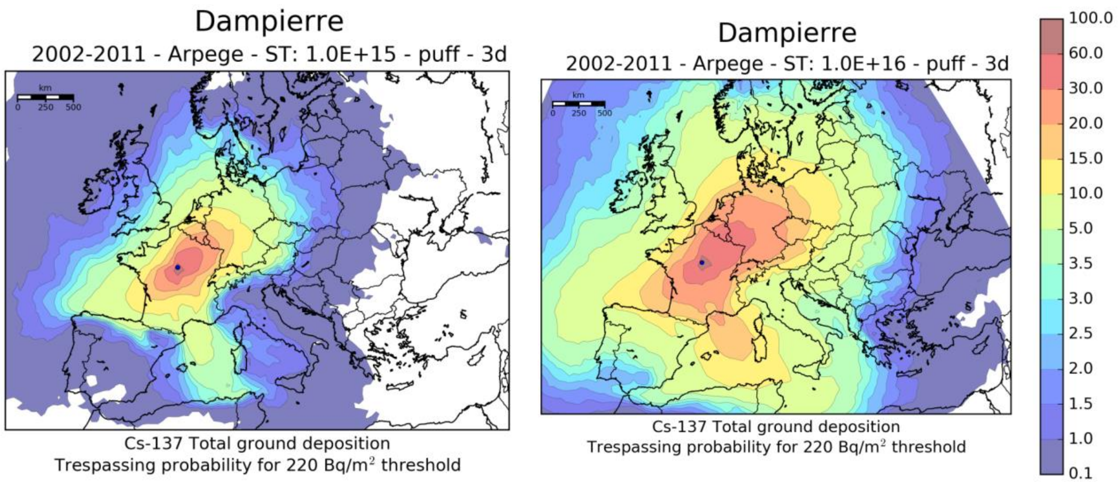
- The «equivalent» 137Cs ground deposition threshold, taking in account the decay data, was evaluated:

$$(CL_{137Cs})_{lim} = 2.4E+02\ [Bq/m^2]$$ (Fukushima case: 3 Units)

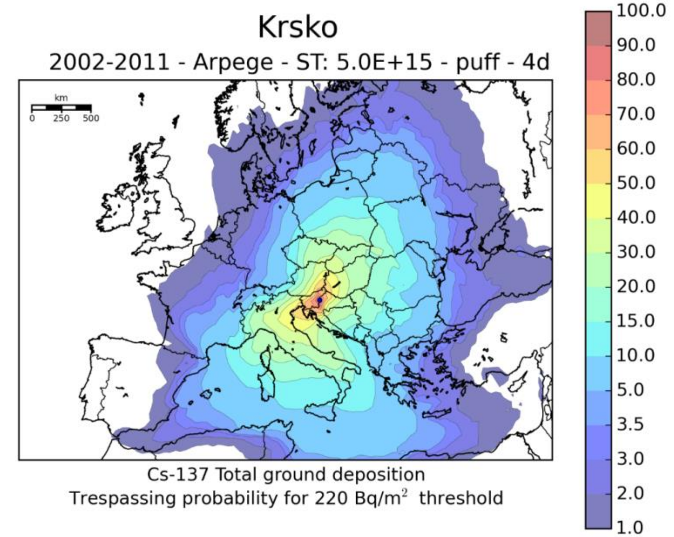
- Using one unit, the ground deposition threshold is lowered up to:

$$\boxed{(CL_{137Cs})_{lim} = 2.2E+02\ [Bq/m^2]}$$ (Fukushima case: 1 Units)

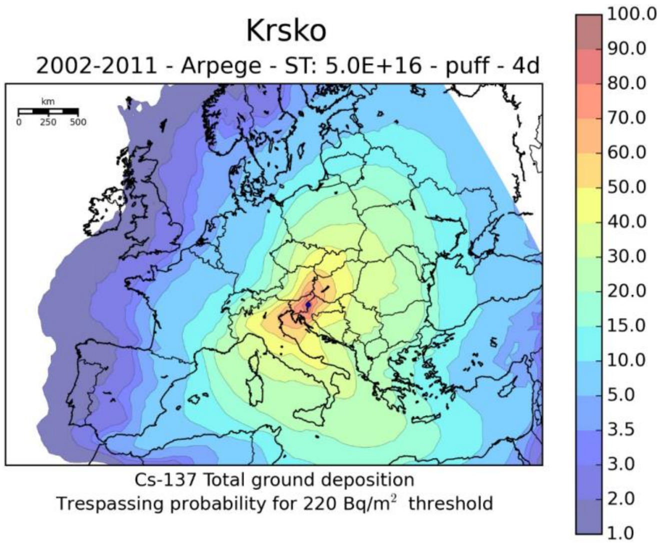
- Achievable results:

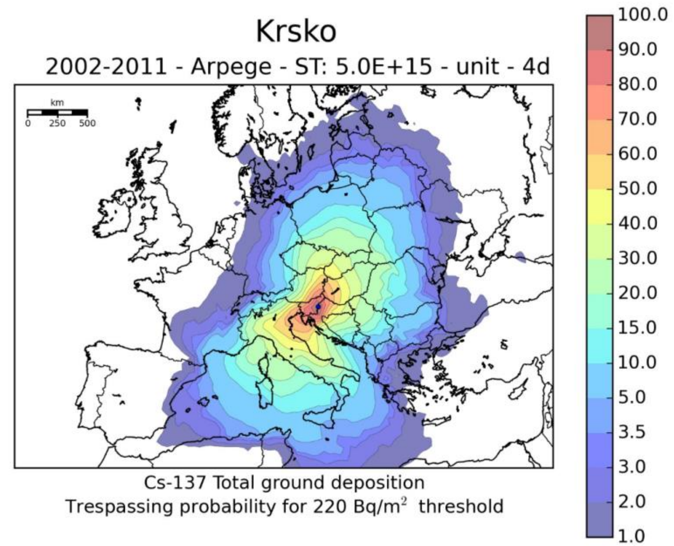


Statistical analysis - results



- ST dynamics of the Unit type results in a major near-range and minor far-range total ground deposition;
- In some Italian areas the threshold limit is exceeded with a probability higher than 50%;





Deterministic approach – RASCAL 4.3

- RASCAL 4.3 has been used to evaluate the Krško Source Term and some detailed dose maps on the Italian territory;
- RASCAL 4.3 is a fast-running tool used by the Protective Measures Team in the U.S. NRC's Operation Center;
- RASCAL aims to provide a rapid assessment of an accident and help to make decisions on countermeasures;
- RASCAL primary module here used is the «Source Term to Dose» which consists of four sub-modules: Eventy type, Event Location, Source Term, Release path and Metereology;

Deterministic approach – RASCAL 4.3

- *Event type* module:
  - define the type of plant (NPP, Spent Fuel, Fuel Cycle, UF6, Criticality Event) from which the radioactive release comes; the choice has been NPP;
- *Event Location* module:
  - define the geographical location of the NPP and all the necessary plant data to evaluate the Activity Inventory;
  - U.S. LWR data are the only ones already included in the internal RASCAL 4.3 database;
  - The choice of Event Location is dictated by the identification of a *surrogate NPP.*

Deterministic approach – RASCAL 4.3

- *Surrogate NPP*:
  - plant already available in RASCAL internal database which differs from the real plant only as regard actual power and actual core average burnup;
  - This means to find among the U.S. fleet a Krško-like (i.e. Westinghouse 2-loops) NPP;
  - The severe accident analysis has been performed with the U1 of Point Beach Station (PB-U1) which is the youngest U.S. Westinghouse 2-loop NPP currently in operation;

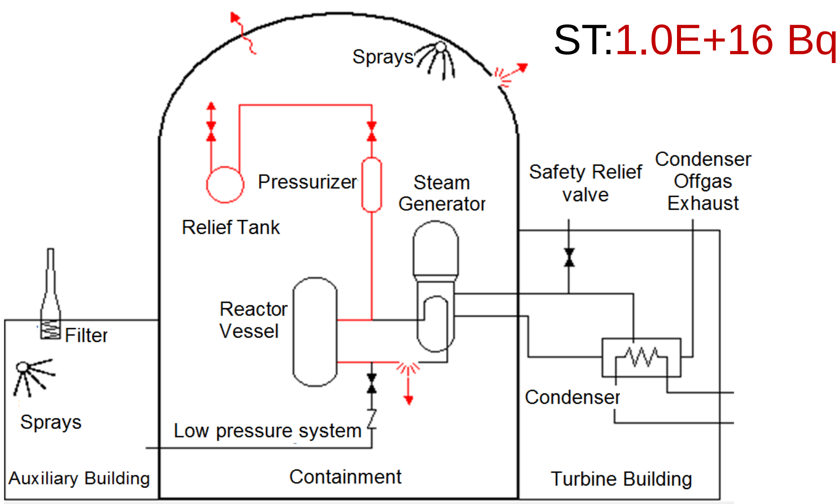
Parameters	Data
Reactor Type	PWR
Ther. power limit (MWth)	1800
Reactor vendor	Westinghouse 2-loop
Operating license issued	10/05/1970
Renewed license issued	12/22/2005
Containment	
Containment type	PWR, Dry
Containment volume	28317 m^3
Design pressure	4.137E+05 Pa
Steam Generator	
SG type	U-Tube
SG water mass	42184 kg
Fuel	
Number of FA	121
Number FR per assembly	235 (16x16)
Krško-like parameters	
Power (MWth)	1994
Core average burn-up (MWd/MTU)	22014

Deterministic approach – RASCAL 4.3

- *Source Term* module:
  - Define the calculation route to evaluate the time-dependent ST;
  - LOCA is the chosen Source Term's sub-module; it's based on reactor conditions and on the procedures described in NUREG-1228 and NUREG-1945;
  - LOCA allows to specify the SCRAM, the core uncovery and recovery times and methods used for core damage estimation; (cladding failure, core melt, vessel melt through);
  - In the present work, no-recovery option has been used.

Deterministic approach – RASCAL 4.3

- *Release path* module:
  - Defines the release pathway of the radionuclide inventory to the environment and the time-dependent emission events;

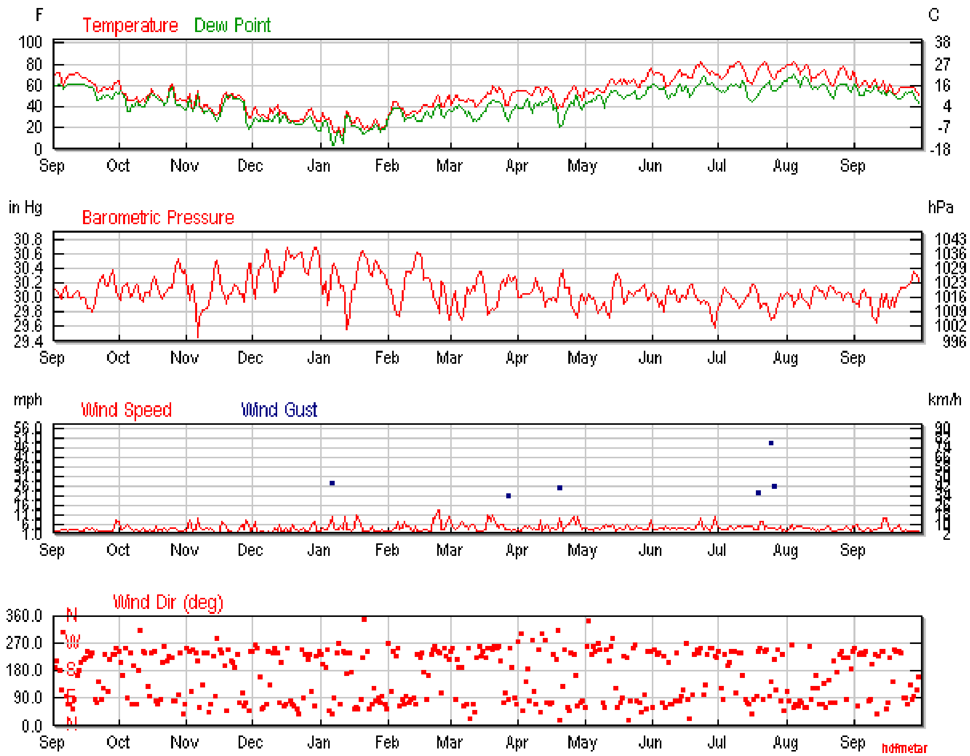


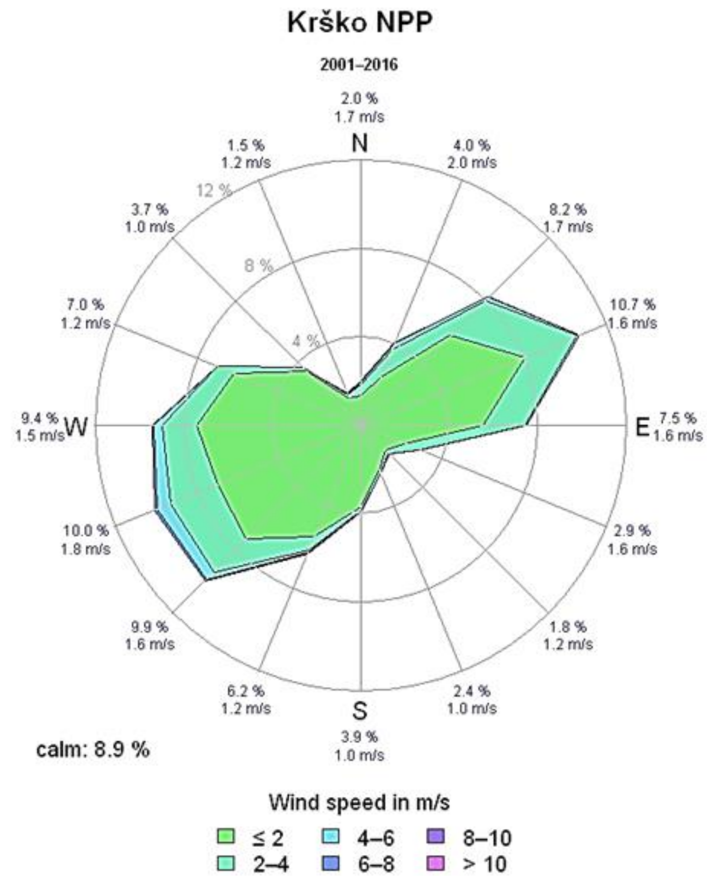
Event	ΔT since SCRAM [h]	[min]	Notes
SCRAM	0	00	-
Core uncovery	6	00	No-recovery
Leak Rate [%Vol]	6	00	Design (0.40%/d)
Sprays	6	00	on
Sprays	9	00	off
Leak Rate [%Vol]	12	00	Total failure (100%/d)

  - The sequence is one of the most severe accident scenarios (i.e. high-level ST @ total failure after only 12 hours since SCRAM).

Deterministic approach – RASCAL 4.3

- Krško weather conditions:





– Tavg = 11 °C; Main wind directions = from ENE or from WSW

Deterministic approach – RASCAL 4.3

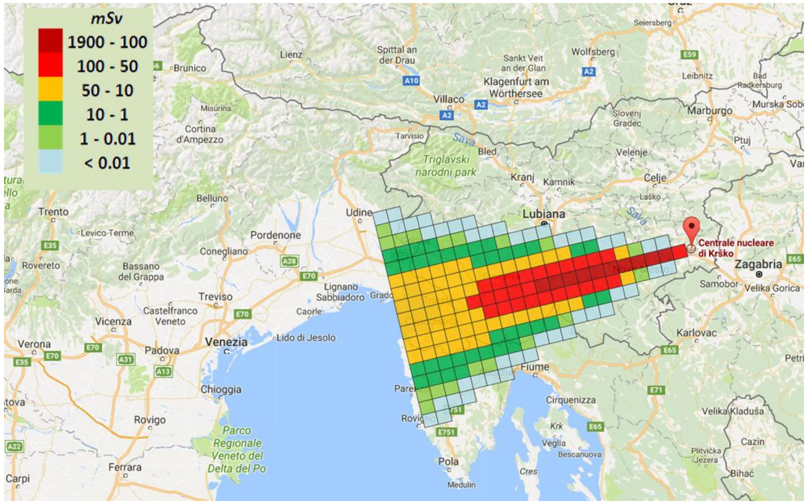
- *Meteorological* module
  - Define the parametric conditions for the transport calculation;
  - Gaussian plume model (TADPLUME) is used near the release point; a lagrangian puff model (TADPUFF) is instead used at longer distances;
  - The transport time has been set to 96 hours since release start;

Type	Name	Description					
Predefined data	Standard	Class Stability	Wind speed [m/s]	Precipitation	Temp. [°C]	Relative humidity [%]	Orography
		D	1.8	No	21	50	Flat terrain

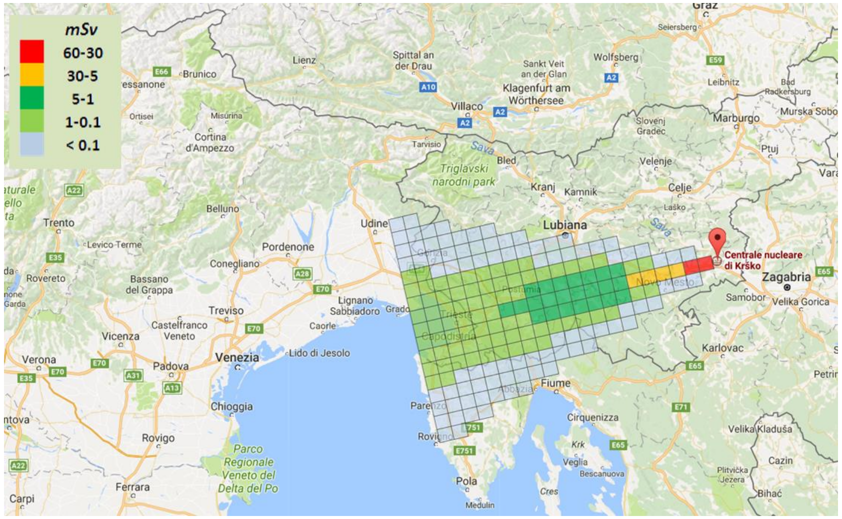
  - This atmospheric dataset is a good approximation of the one-year average Krško weather conditions.

Deterministic approach – Results

- Determistic results:
  - RASCAL evaluates the time integrated air concentration on a 8x8 km unit cells map for a distance of 160 km from the release point;
  - The results show the TEDE and Cloudshine dose maps;



TEDE dose map
(ST 1E+16 Bq, std. meteorology)

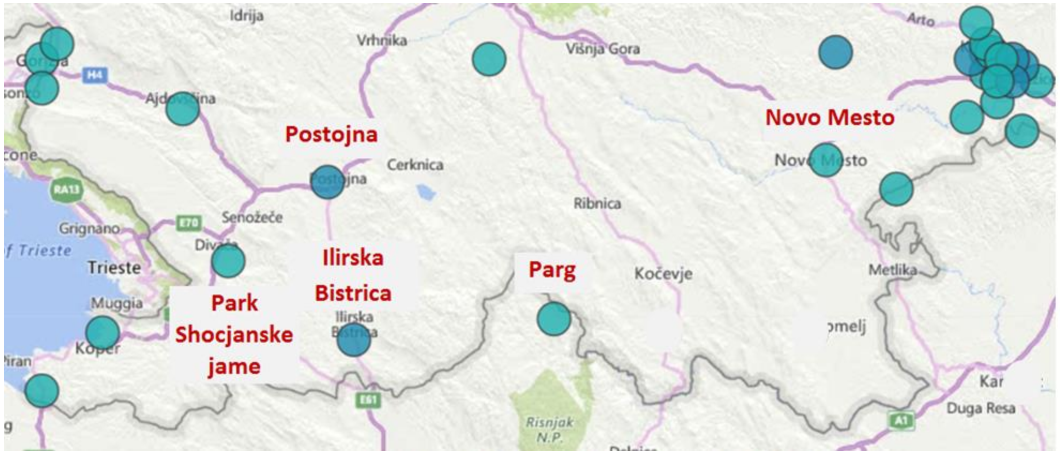


Cloudshine dose map
(ST 1E+16 Bq, std. meteorology)

Forecast alert methodology

- The TEDE map suggests a possible overrunning of the emergency limits in the Italian territory;
- The idea is to use the gamma rate values (EURDEP stations) to get an alert notice of at least 12 hours since the event;

Gamma stations	Distance from Trieste [km]
Park S. J.	17
Postojna	36
Ilirska Bistrica	38
Parg	66
Novo Mesto	110



EURDEP stations whitin the RASCAL simulation domain

Forecast alert methodology

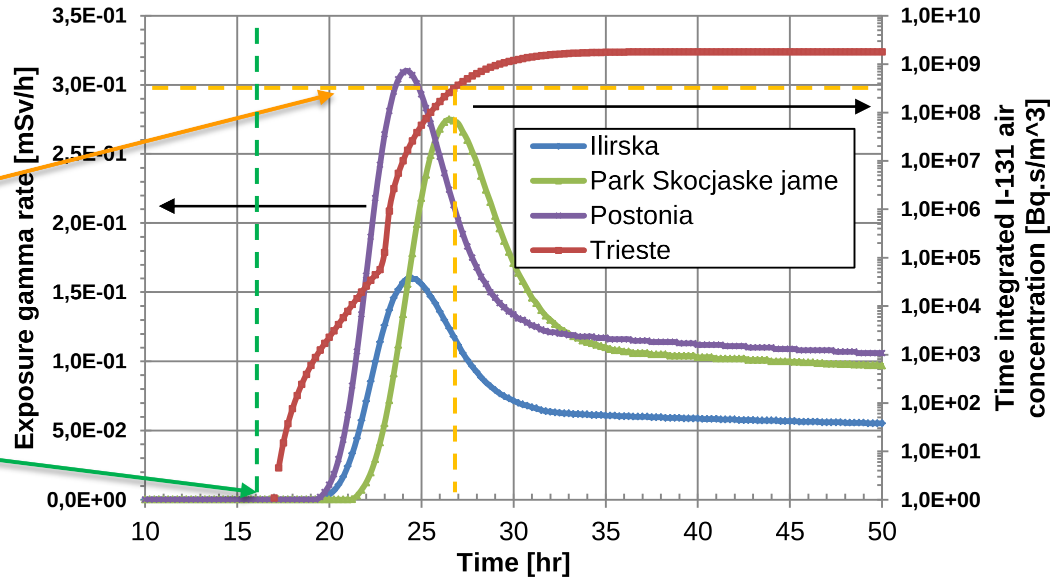
- Two alert criteria:
  - «Threshold value»: a threshold value reached in a specific Italian area as alert criteria for the gamma dose-rate stations;
    - Thresholds criteria is ideally applicable only if the radiological quantity to evaluate is the same measured by the stations;
  - «Warning time»: to fix a specific warning time and evaluate the measurements that a given gamma dose-rate station should give 12 hours before the threshold overrunning in Italy;
  - The method is effective in the hypothesis of weak variance of the atmospheric conditions during the 96 hours of the transport.

Forecast alert methodology

- «Warning time» methodology:
  - EURDEP stations at less than 40 km from Trieste;
  - The stations background values are of the order of 100 nSv/h;
  - The stations cannot provide a radiological alert more than 3-4 hours in advance from the event in Trieste;

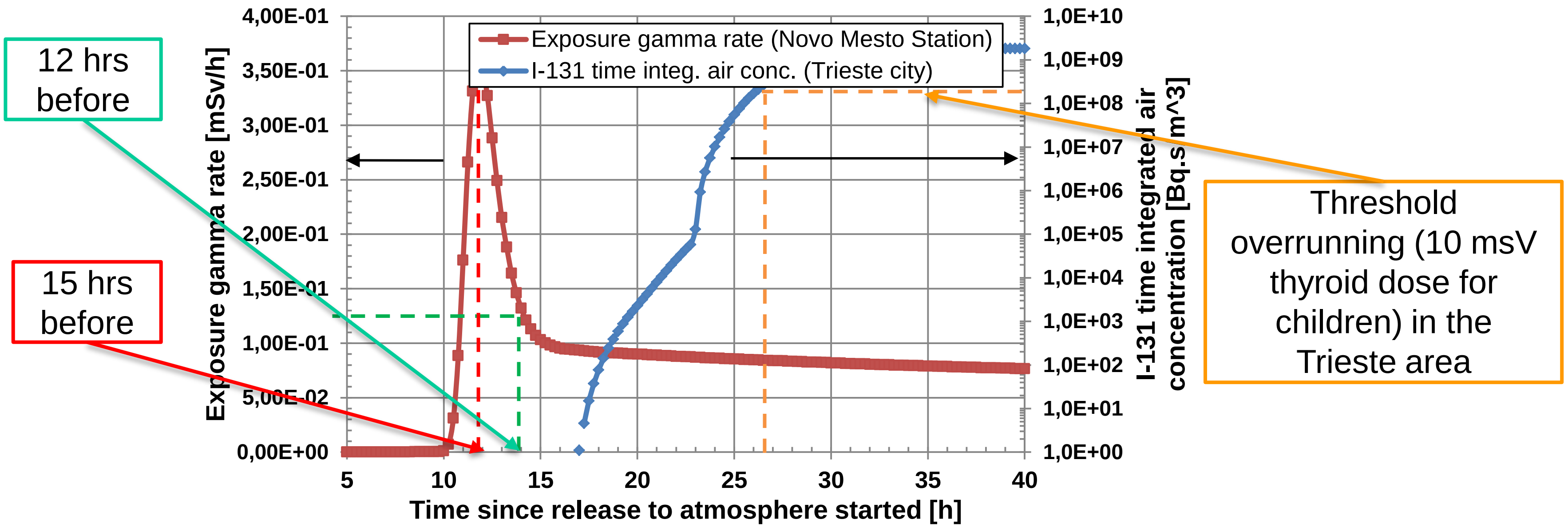
Threshold overrunning (10 mSv thyroid dose, children) in the Trieste area

12 hours before threshold overrunning in the Trieste area



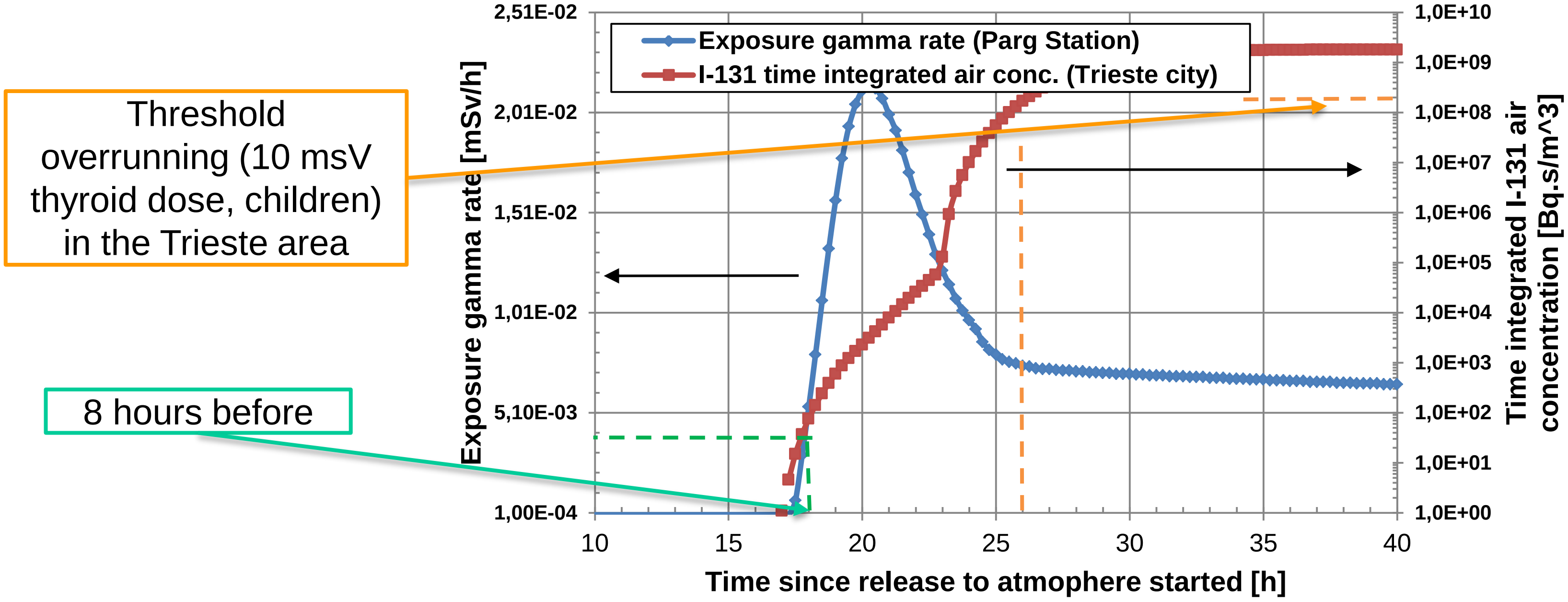
Forecast alert methodology

- «Warning time» methodology:
  - EURDEP stations at more than 40 km from Trieste;
  - **Novo Mesto** station can give an alert 12 hours in advance;
  - If the indicator is the peak value, the alert time can reach 15 hours;



Forecast alert methodology

- «Warning time» methodology:
  - **Parg** allows an alert indication no more than 8 hours in advance;
  - **Parg** could be used to confirm an alert signal of Novo Mesto or as a redundant alert station.



Conclusions

- The statistical approach can provide a huge amount of information based on a reliable scientific process;
- An accident database constructed with this approach can be a reliable assessment tool for decision makers ;
- The analysis shows that in some north-eastern and central Italian areas there is a 50% likelihood of trespassing the «equivalent» Cs-137 threshold limit for leaf vegetables;
- A deterministic analysis on the Trieste district reveals that there may be a need to take countermeasures (iodine prophylaxis);
- The proposed alert methodology (EURDEP stations) shows that it is possible to get an alert notice 12 hours in advance with respect to a threshold overrunning in the Trieste district.