Italian National Agency for New Technologies,
Energy and Sustainable Economic Development

MACCS2 preliminary analysis to evaluate the impact on Italy of a severe accident at Krško NPP

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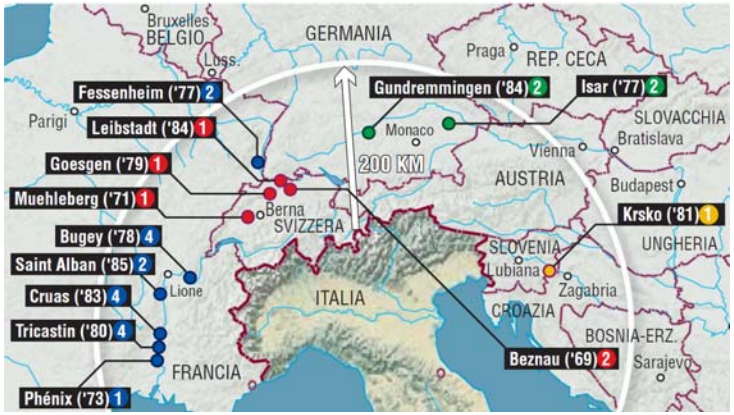
Outline

- Overview
- Introduction
- MACCS2 code general options
- Site-related options:
  - Meteo data
  - Morphology data
- Comparison 16 vs 32 polar grid sectors
- Results
- Conclusions

Overview

- Italy is surrounded by **26 foreign active NPPs at less than 200 km from its borders**;



Country	*NPPs*	*Technology*	*Thermal power*	*Electric power*
[-]	*[-]*	*[-]*	*[MWth]*	*[MW]*
France	16	PWR	46300	15300
Switzerland	5	PWR-BWR	9360	2070
Germany	4	PWR-BWR	14200	4860
Slovenia	1	PWR	2000	660
TOTAL	26	-	71860	22890

- It's therefore necessary to have: **provisions, experience, and capabilities to foresee in real-time the consequence of a severe-accident at one of the 26 NPPs**;
- In this context, ENEA has recently started to use the **MACCS2 code** to strengthen its capabilities in the field of Emergency Preparedness and Response (EP&R).

Introduction – Krško NPP

- Background: ENEA is developing a model for the Krško NPP area in order to perform **PSA-3 studies** of the impact over Italy;
- Source Term: simplified ST for a preliminary impact evaluation [**131-I** (1.0E+17 Bq) and **137-Cs** (1.0E+16 Bq)], single release of 1 hour duration;
- Metereological data: 1 year of hourly weather data at Krško NPP obtained through the **History+** service of **Meteoblue** (https://www.meteoblue.com/it/historyplus);
- Spatial grid: 22 radial sectors and 32 compass directions up to **140 km** from Krško NPP;
- Code: The calculations are carried out with the NRC code (**MACCS2/WinMACCS3.11.2**).

MACCS2 – general options

- The MACCS2 options have been set according to Best Practices (NUREG/CR-7009) and NRC (LNT sample problems) suggestions:

Main category	Category	Subcategory	Form	Parameters	Note
GENERAL					
	Properties				
		Scope	Early Consequences		
		Transport	Dispersion	Look-up Tables	Tadmor and Gur lookup table (NUREG-1150)
			Plume Meander	US-NRC Regulatory Guide 1.145	Plume meander model used in the Regulatory Guide 1.145 .
		Weather model	Weather from file	Non-uniform Bin Sampling	Mixing height based on time of the day.

MACCS2 – general options

Main category	Category	Subcategory	Form	Parameters	Note
		Plume/Source	Plume Rise	Power Model	Original MACCS model
		Site Data	Import from file	-	Krsko site-related land fraction with 32 compass directions
		Dose	Dose Response model	LNT	-
		Wind Rose		Default	Wind rose probabilities for each weather sampling bin constructed from the meteorological data file
	File Specifications		Meteorological file	Krsko_2018_MxHt_60min.txt	Meteorological hourly data file from Meteoblue for the Krsko site.
			Site File	Krsko_Site_32.inp	(32 angular directions)
			Dose conversion factor file	FGR-13	Best practice is to use the FGR-13 DCF file.

And so on ...

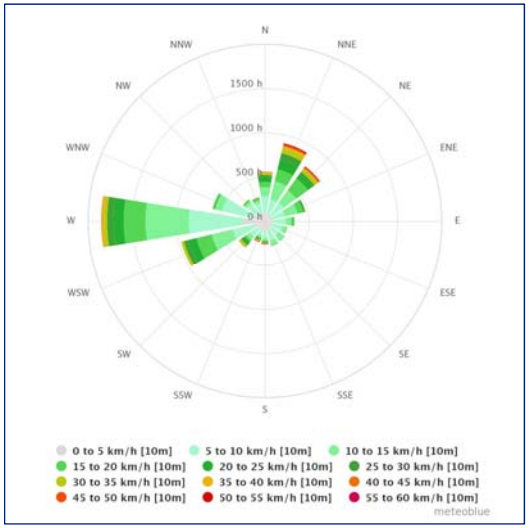
Site-related options: meteo data (1)

Metereology conditions Krško area – 2017:

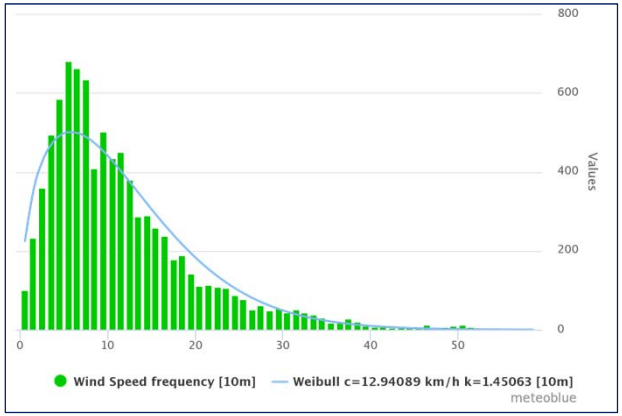
- Python post-processing of Meteoblue data for MACCS2 format:

  (i.e., **wind direction)**:

Meteo Blue Format (direction from which the wind blows)		MACCS2 Format (direction the wind is blowing toward)	
Cardinal direction	Degree Direction	Cardinal direction	MACCS2 format
N	348.75 – 11.25	N	1
NNE	11.25 – 33.75	NNE	2
NE	33.75 – 56.25	NE	3
ENE	56.25 – 78.75	ENE	4
E	78.75 – 101.25	E	5
ESE	101.25 – 123.75	ESE	6
SE	123.75 – 146.25	SE	7
SSE	146.25 – 168.75	SSE	8
S	168.75 – 191.25	S	9
SSW	191.25 – 213.75	SSW	10
SW	213.75 – 236.25	SW	11
WSW	236.25 – 258.75	WSW	12
W	258.75 – 281.25	W	13
WNW	281.25 – 303.75	WNW	14
NW	303.75 – 326.25	NW	15
NNW	326.25 – 348.75	NNW	16



Wind Rose (10 m above) – source: meteoblue



Wind Speed Frequency – source: meteoblue

Site-related options: meteo data (2)

Stability was evaluated on the basis of the «Pasquill-Gifford» classification:

Meteoblue data (Krsko, 2017)

h	v	c	r
0	3.3	4	000.00
1	3.7	1.2	000.00
2	3.9	0.6	000.00
3	3.9	0	000.00
4	3.8	0	000.00
5	3.6	0	000.00
6	3.6	0	000.00
7	3.6	0	002.67
8	3.4	0	098.79
9	3.1	0	226.06
10	1.7	0	317.73
11	1.7	0	367.57
12	1.2	0	370.24
...	...	...	...
15	10.4	0	096.12
16	10.8	0	004.45
17	10.7	0	000.00
18	10.6	0	000.00
19	10.3	0	000.00
20	9.9	6	000.00
21	9.6	57	000.00
22	9.4	100	000.00
23	8.9	91	000.00

IN

Python post-processing

Table 1. Pasquill-Gifford (PG) Day Time Classification Scheme

Wind Speed (at 10m) (m/s)	Day Time Solar Insolation (W/m^2)			Radiation Overcast
	Strong >600	Moderate 300-600	Slight < 300	
<2	A	A-B	B	C
2-3	A-B	B	C	C
3-5	B	B-C	C	C
5-6	C	C-D	D	D
>6	C	D	D	D

Table 2. Pasquill-Gifford (PG) Night Time Classification Scheme

1 Hr Before Sunset or After Sunrise	Cloud Cover (Oktas) Night-time		
	0 -3	4 – 7	8
D	F or G	F	D
D	F	E	D
D	E	D	D
D	D	D	D
D	D	D	D

Source: Muir, 2004.

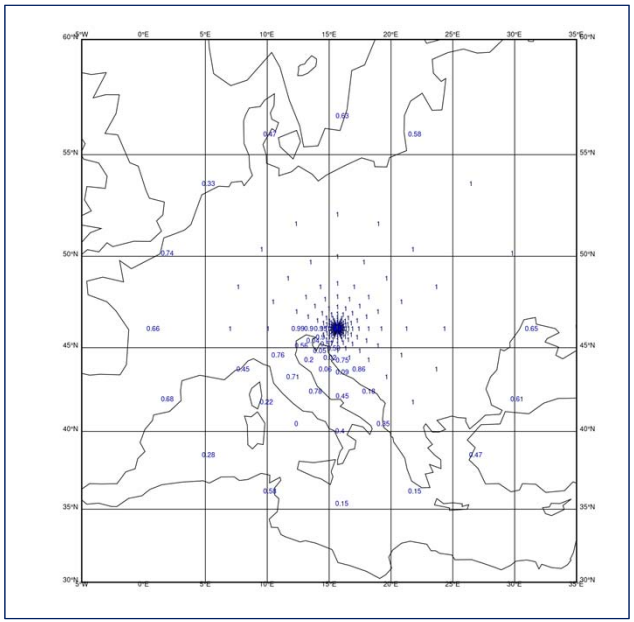
OUT

Stability_out (MACCS2 format)
s
5
5
5
5
5
4
3
3
3
3
2
2
2
...
2
2
2
2
3
4
4
4
4

Site-related options: morphology

Land conditions – Krško area :

- Land-Sea mask from European Center of Medium Wheater Forecast (ECMWF) using the Metview python module for the evaluation of land/water fraction for each spatial grid element



```
LAND FRACTION
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 0.63
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 0.58
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 0.65
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 0.61
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 0.47
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 1.00 1.00 0.86 0.18 0.35 0.15
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 1.00 0.60 0.09 0.45 0.40 0.15
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 0.59 0.70 0.06 0.78 0.00 0.58
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 0.57 1.00 0.20 0.71 0.22 0.28
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 0.90 1.00 0.56 0.76 0.45 0.68
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 0.95 1.00 0.99 1.00 1.00 0.66
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 0.74
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 0.33
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 0.47
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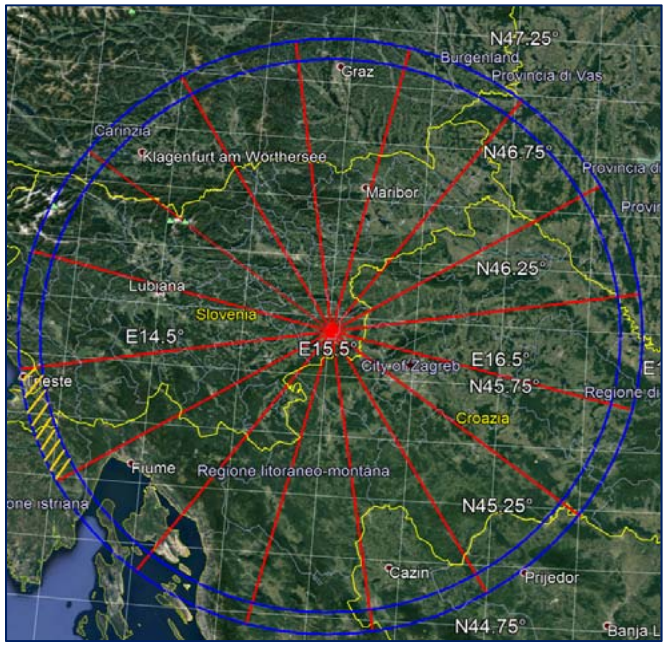
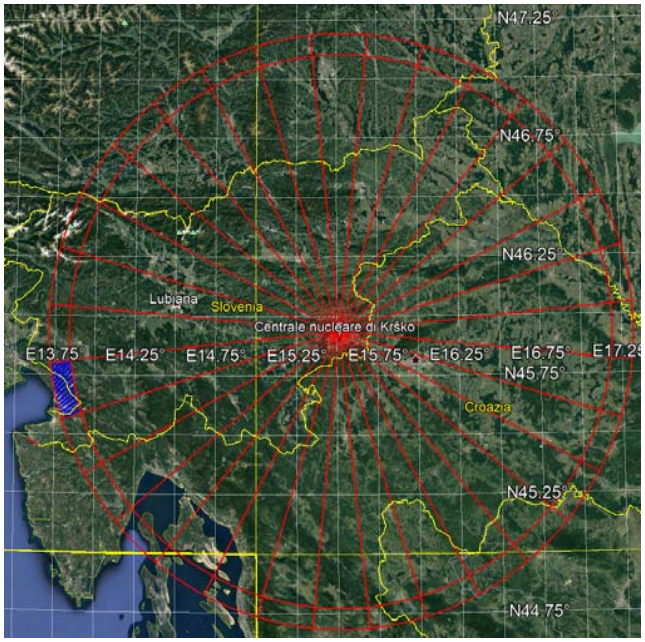
Comparison 16 vs 32 polar grid directions

Two possible computational grid have been explored:





Krško Polar Grid: source Google Earth Pro – 16 and 32 sectors

22 radial directions up to Italy (140 km)

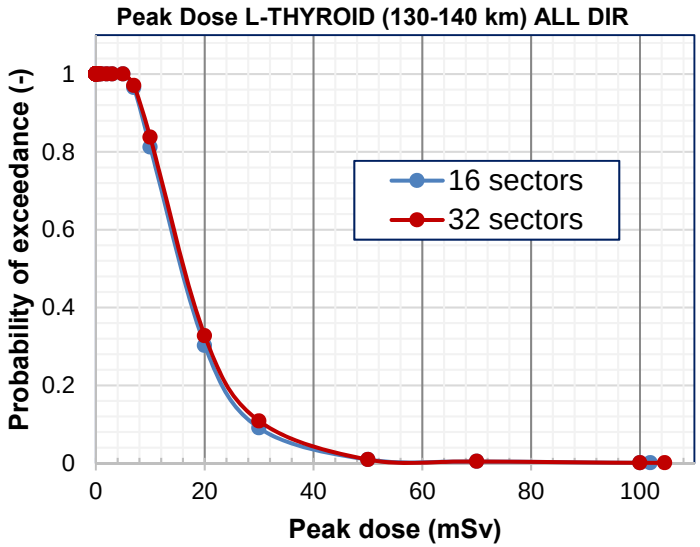
[km]	
0.16	MACCS Best Practices
0.52	
1.21	
1.61	
2.13	
3.22	
4.02	
4.83	
5.63	
8.05	
11.27	
16.09	
20.92	
25.75	
32.19	
40.23	
48.28	
64.37	
80.47	
112.65	
130.00	Italy area
140.00	

Comparison 16 vs 32 polar grid directions

16 and 32 sectors are not directly overlapped...

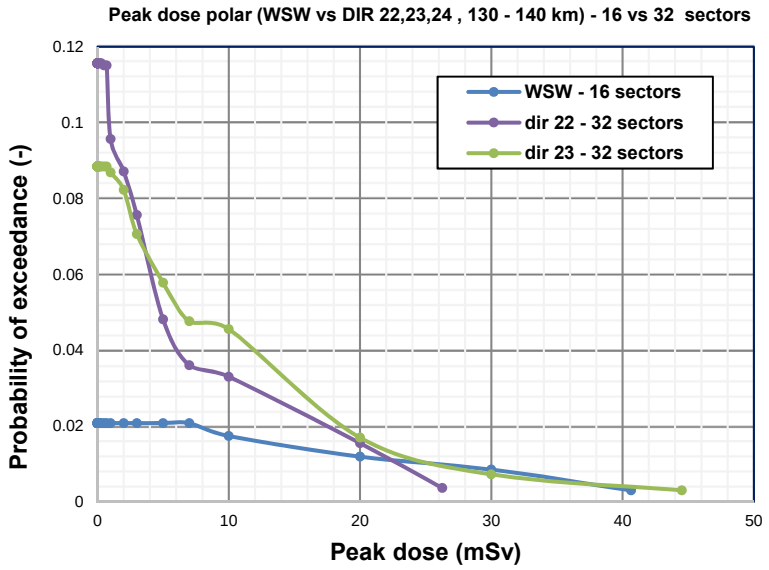
16 vs 32 MACCS2 compass directions

...but the results, at fixed weather conditions, are the same over a whole radial ring.



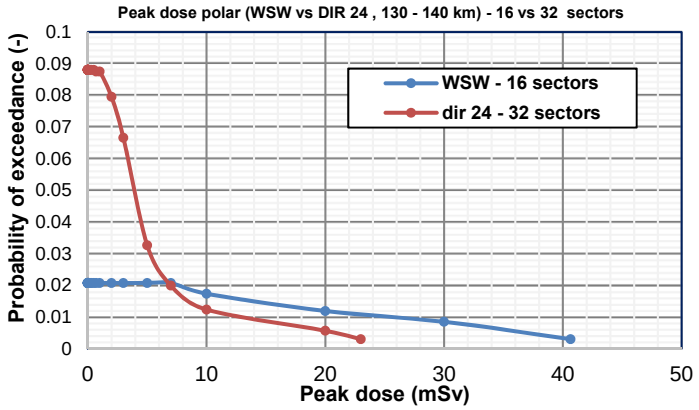
Comparison 16 vs 32 polar grid directions

More conservative (higher probabilities vs Peak dose) results for the sectors belonging to the 32 MACCS2 compass direction scheme.



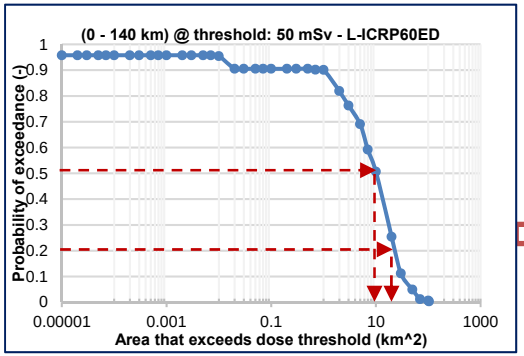
The Italian area is better contained in a 32 sector subdivision of the MACCS2 polar gird:

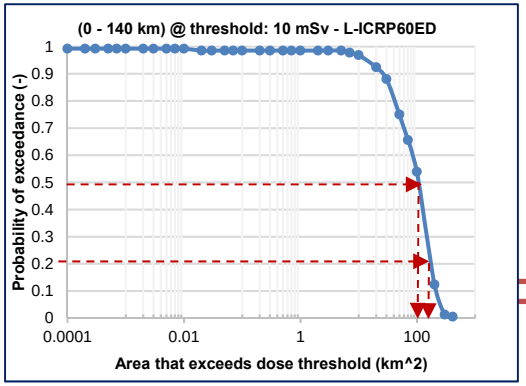
Polar grid subdivision	Sector (130-140 km)	Italian area
16	WSW	¼ of total sector area
32	DIR 24	½ of total sector area



Results – area extension for protective actions

Area extension for protective actions:



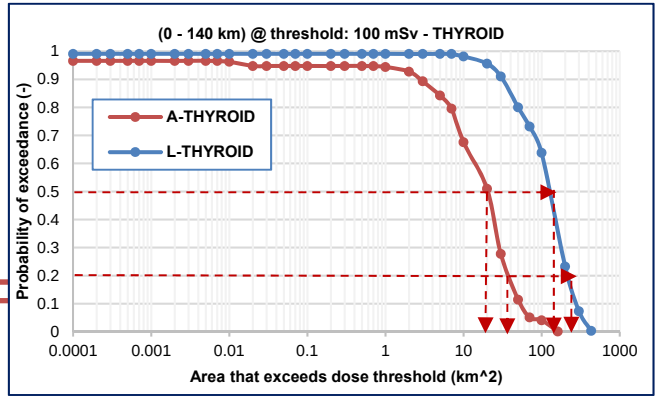


Protective actions in area with a radius of 5 – 10 km from the emission source

Protective action	Threshold (IAEA)	Area (50%) [km^2]	Area (20%) [km^2]	Note (-)
Evacuation	50	10	13	TEDE
Sheltering	10	100	103	L-ICRP60ED (40d)
Iodine pills	100	20	22	A-TYHROID
Iodine pills	100	110	112	L-THYROID (40d)

International dose emergency level for the adoption of protective actions
source: «Emergenze Nucleari e Radiologiche» (Ispra)

Azione protettiva	Livelli di intervento di dose efficace o equivalente (mSv)		
	ICRP(*)	IAEA(**)	Unione Europea(***)
Evacuazione	50 – 500 (500 - 5000 pelle)	50	da alcune unità ad alcune decine
Riparo al chiuso	5 - 50	10	da alcune decine ad alcune centinaia
Iodoprofilassi	50 – 500 (tiroide)	100 (tiroide)	da qualche decina ad alcune centinaia



Comparison results – IdX vs MACCS2

- ENEA, thanks to a Cooperation Agreement with IRSN, has access to IdX code to perform statistical studies of neighboring NPPs;

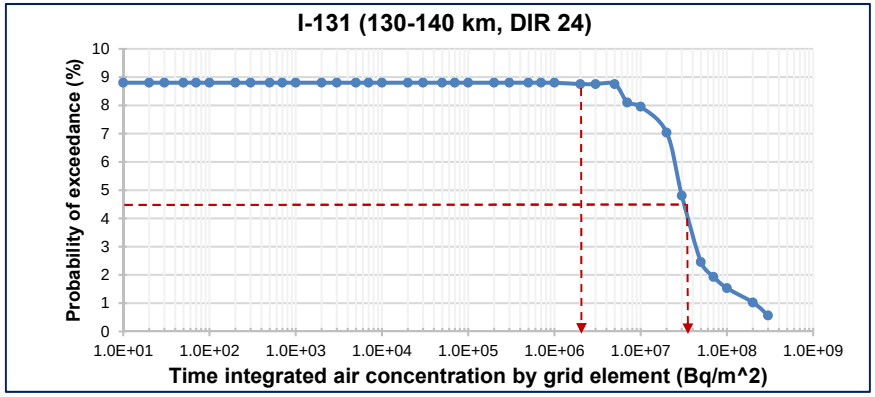
- IdX is an Eulerian atmospheric transport code which uses real 3-D weather data (0.1° or 0.5° resolution, over different domain extensions) to evaluate the atmospheric dispersion of Source Terms (STs);

- IdX takes into account the radioactive filiation and decay during the transport, wet scavenging and dry deposition and includes finer physical models directly calling on more than 20 advanced meteorological parameters such as relative humidity or height of clouds;

- ENEA uses IdX with historical data (2002-2011, Meteo-France data) to perform statistical studies of consequences to rank foreign NPPs and to optimize preparedness provisions.

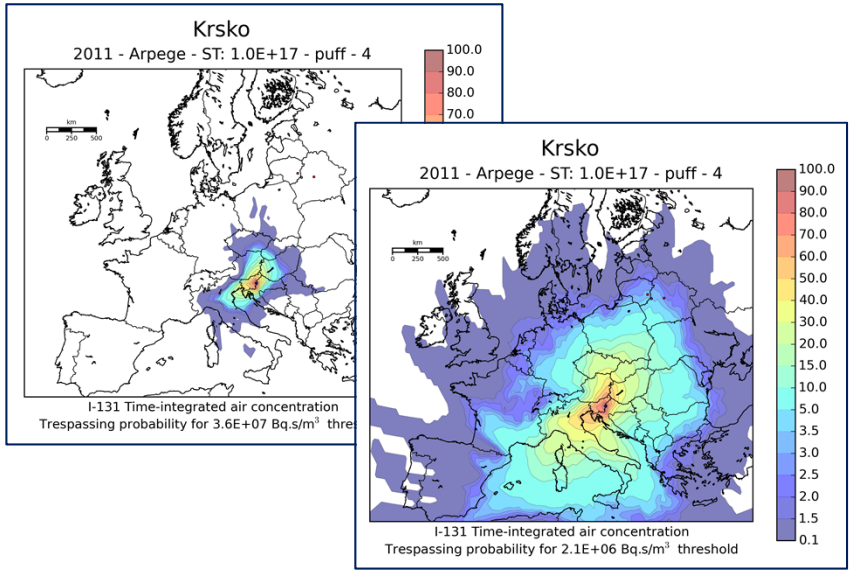
Comparison results – IdX vs MACCS2

Comparison results between MACCS2 and IdX code:



Statistical analysis – MACCS code

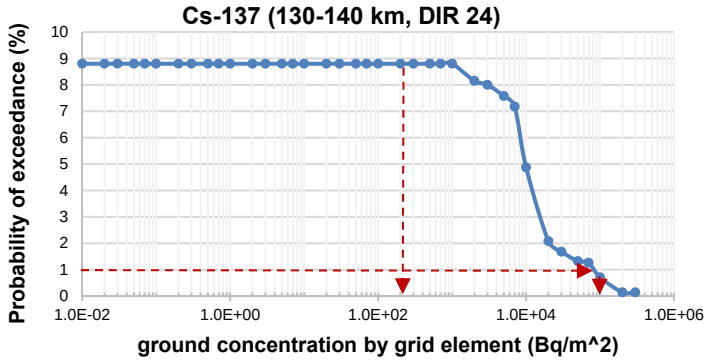
Code	Isotopes	Threshold (Bq.s/m^3)	Trespassing probability (%)	year	Note
MACCS	I-131 «equivalent»	3.6E+07	4.5	2011	Inhalation (1 mSv) Tab. 5.14 CeVAD
IdX	I-131 «equivalent»	3.6E+07	30-40	2011	
MACCS	I-131 «pure»	2.1E+06	9	2011	
IdX	I-131 «pure»	2.1E+06	60-70	2011	



Statistical analysis – IdX code

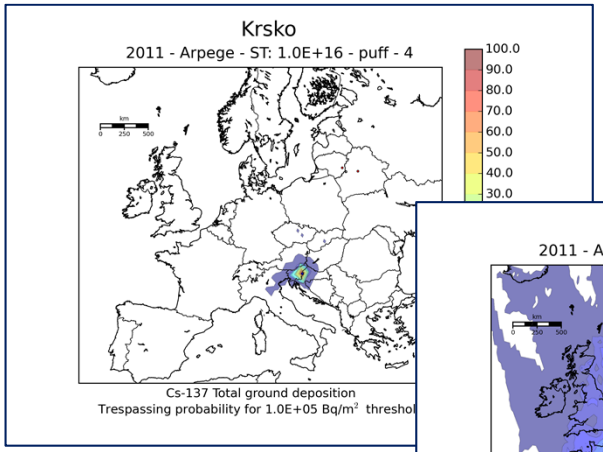
Comparison results – ldX vs MACCS2

ldX – MACCS2 Codes comparison:

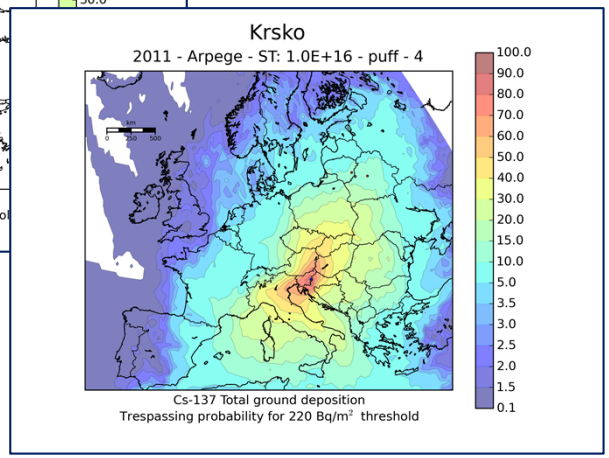


Statistical analysis – MACCS code

code	Isotope	Threshold (Bq/m^2)	Trespassing Probability (%)	Time (year)	Note
MACCS	Cs-137 «equivalent»	220	9	2017	Inhalation (1 mSv) Tab. 5.14 CeVAD
ldX	Cs-137 «equivalent»	220	60-70	2011	
MACCS	Cs-137 «pure»	1.00E+05	1	2017	
ldX	Cs-137 «pure»	1.00E+05	1.5 - 2.5	2011	



Statistical analysis – ldX code

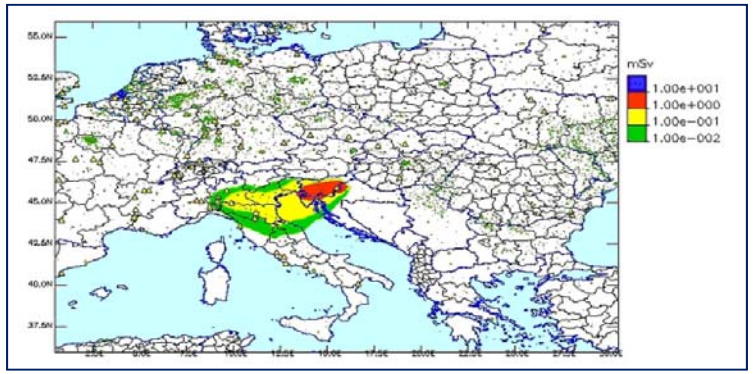


- MACCS seems to show a lower trespassing probability in comparison with ldX code;
- Anyway, ldX doesn't provide very accurate results for distances within 1-3 cells (50 ÷ 150 km) from the emission source.

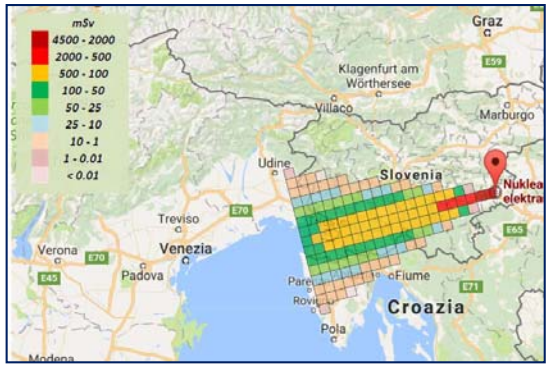
Comparison results – Apollo, Rascal vs MACCS2

- **APOLLO** (**A**ccidental **R**elease **I**mpact **E**valuation **S**ystem) is the code used by the Italian Regulatory Body for the evaluation of the atmospheric dispersion of radionuclides.

- **RASCAL** (**R**adiological **A**ssessment **S**ystem for **C**onsequence **A**na**L**ysis) was developed and currently used by NRC for making dose projections for atmospheric releases during radiological emergencies. It's uses a Gaussian plume model on a 2-D meteo data.



Effective inhalation dose – (I-131, pop. Children)



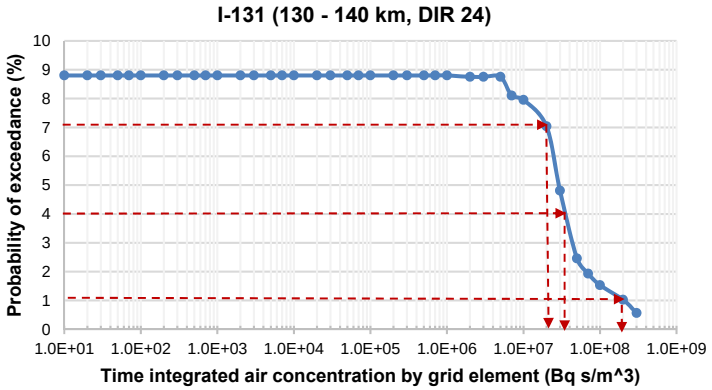
Equivalent thyroid dose – (I-131 pop. Children)

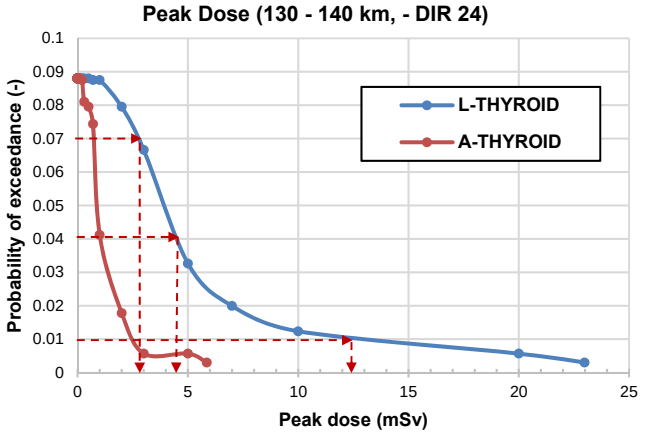
Comparison results – Apollo, Rascal vs MACCS2

RASCAL – APOLLO – MACCS2 Codes comparison:

Population group	Dose type (mSv) (I-131)	APOLLO	RASCAL 4.3	MACCS2 (7%)	MACCS2 (4%)	MACCS2 (1%)	Notes
Children	Thyroid equivalent dose	27	129	5.1	6.8	16	FGR-13 Chronic dose
Adults	Thyroid equivalent dose	16	76	3	4.5	12	FGR-13 Chronic dose
Children	Inhalation effective dose	1.5	6.8	0.06	0.1	0.7	Tab. 5.6 @ CeVAD
Adults	Inhalation effective dose	0.8	4.0	0.1	0.2	0.9	Tab. 5.6 @ CeVAD

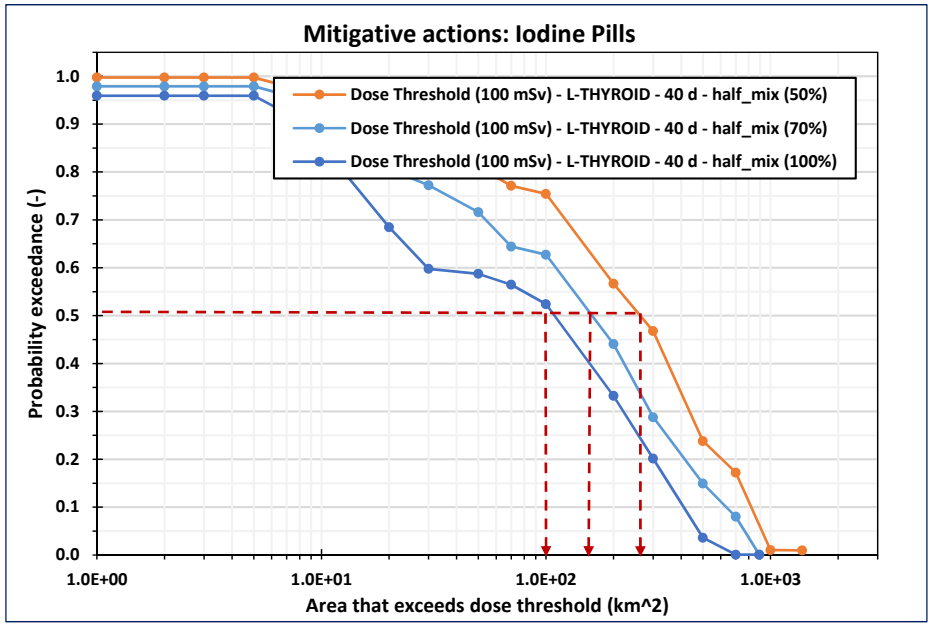
APOLLO	Reference italian code for atmospheric dispersion analysis **Conservative meteo conditions @ Orography YES**
MACCS2	Reference US-NRC code for off-site consequences analysis **Real 1-year hourly meteo conditions @ Orography NO**
RASCAL	Reference US-NRC code for dose and consequences analysis **Extremely conservative meteo conditions @ Orography NO**





Mixing height sensitivity – Krško NPP

Mixing height sensitivity:



Probability of exceedance	Area (Hmix)	Area (Hmix_70%)	Area (Hmix_50%)	Ratio (Hmix_70/Hmix)	Ratio (Hmix_50/Hmix)
	(km^2)	(km^2)	(km^2)	(-)	(-)
70 %	100	150	270	1.5	2.7

WINTER		SPRING		SUMMER		AUTUMN		Hmix reduction
Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	(%)
7.00	6.50	6.00	5.00	10.54	18.90	19.24	14.12	100
4.90	4.55	4.20	3.50	7.38	13.23	13.47	9.88	70
3.50	3.25	3.00	2.50	5.27	9.45	9.62	7.06	50

Note: In the future, it is advisable to evaluate a Mixing Height value as close as possible to the real one in the MACCS's polar grid area.

Conclusion

- A preliminary analysis of the impact of a severe accident ad Krško NPP has been performed with the MACCS2 code;
- The obtained results suggest that MACCS2 code could be used in future as a fast-tool for impact studies and for a PSA-level3 analysis;
- MACCS2 vs ldx code comparisons suggest that MACCS2 seems underestimate the results but further analyses should be performed. Other comparisons suggest that Apollo and RASCAL results are more conservative with respect to MACCS2;
- MACCS2 code evaluation will be performed in the future with: 1) a site-related mixing height; 2) the CHRONC module to estimate the off-site long term effects to the population.

Thanks for your attention!

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