16th EURADOS School, June 15 2023

Belgian Nuclear Research Centre

Johan Camps & Pieter De Meutter

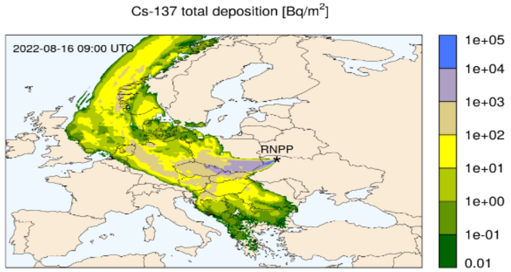
Case studies
The current nuclear risk in Europe

Content - Nuclear Risks

Risk = probability of occurrence x consequences or impact

Event at NPP in Ukraine:

- Focus on impact at larger distances
  - Contamination level
  - Detections at early warning stations



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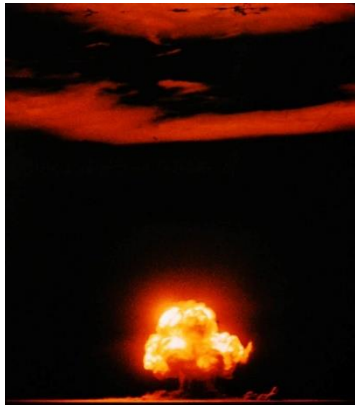

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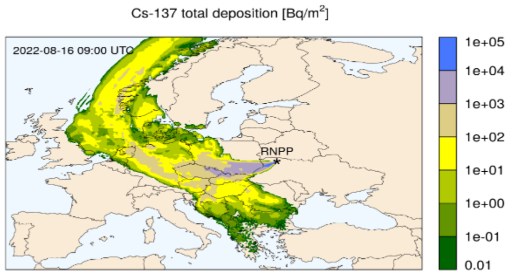

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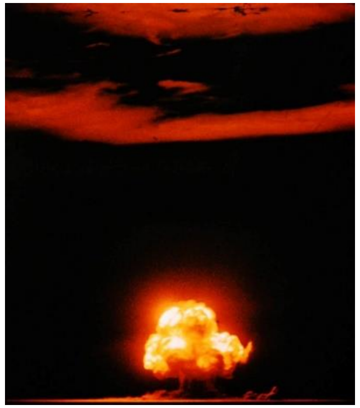


Potential impact from a hypothetical release from a Ukrainian NPP (on Western Europe)

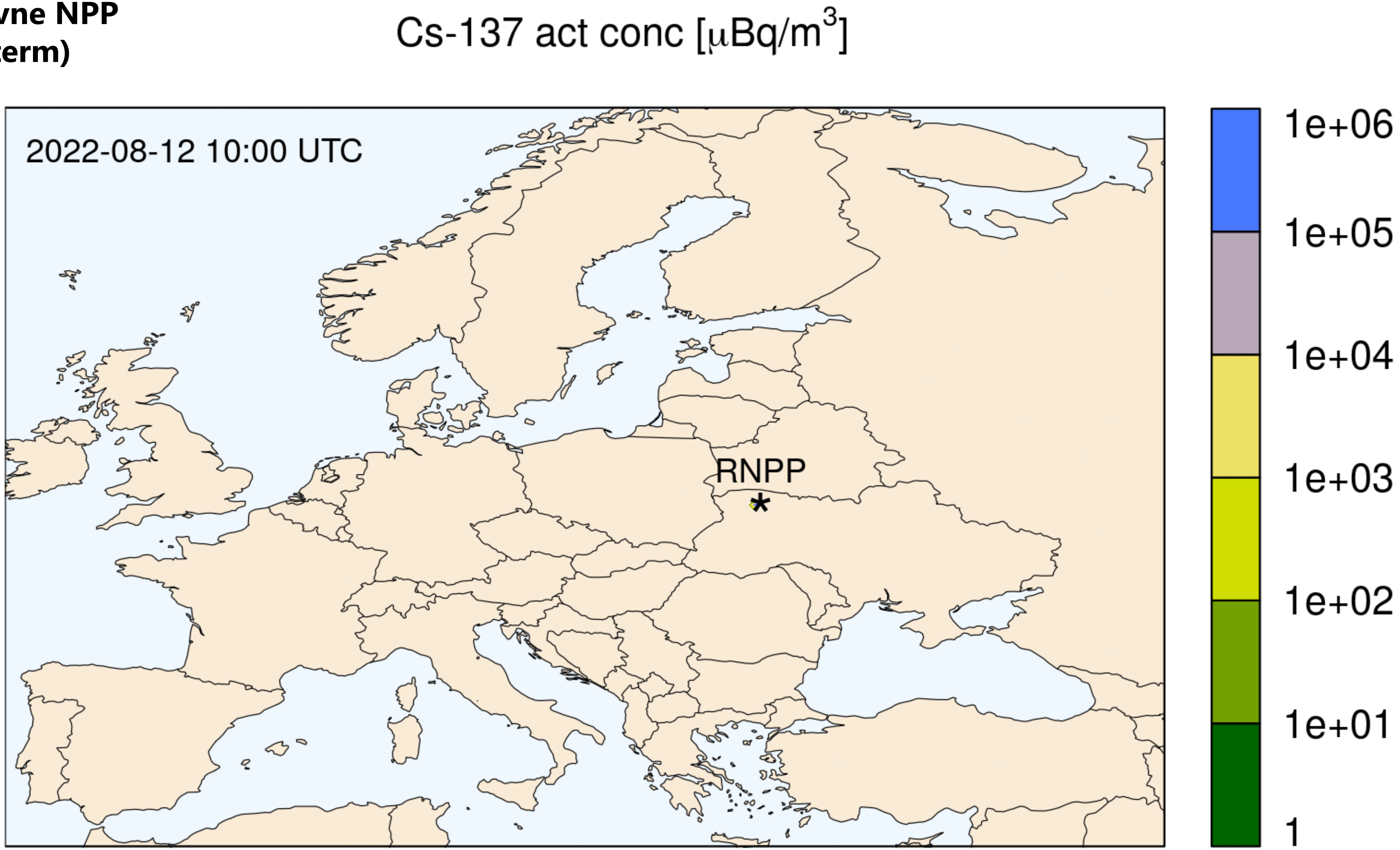
Initiating event: loss of cooling with release from reactors or spent fuel

Calculation set-up:

- Lagrangian stochastic particle model *Flexpart*, coupled with archived numerical weather data from the ECMWF Forecasts
- Simulations for the 4 NPP locations in Ukraine and a 6 hour release of
  - A “passive” air tracer (noble gas): Xe133, Xe135 (Kr85)
  - I131
  - Cs137 (Cs134)
- Total of 6000 simulations: 500 release moments x 3 radionuclide species x 4 locations

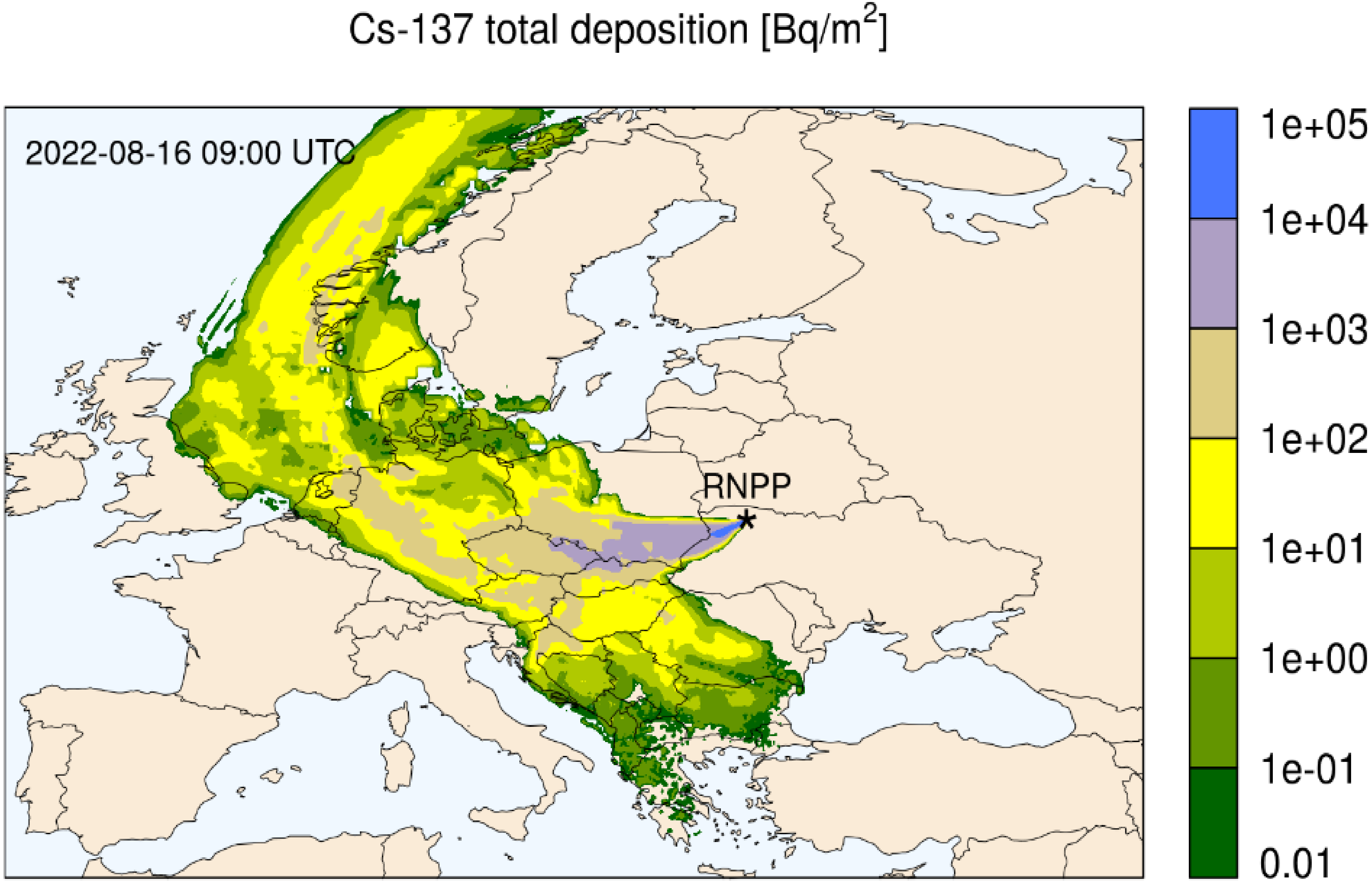
Ouput: probability to exceed certain levels (contamination levels , ambient dose rate from cloud)

Example – Rivne NPP (unit source term)



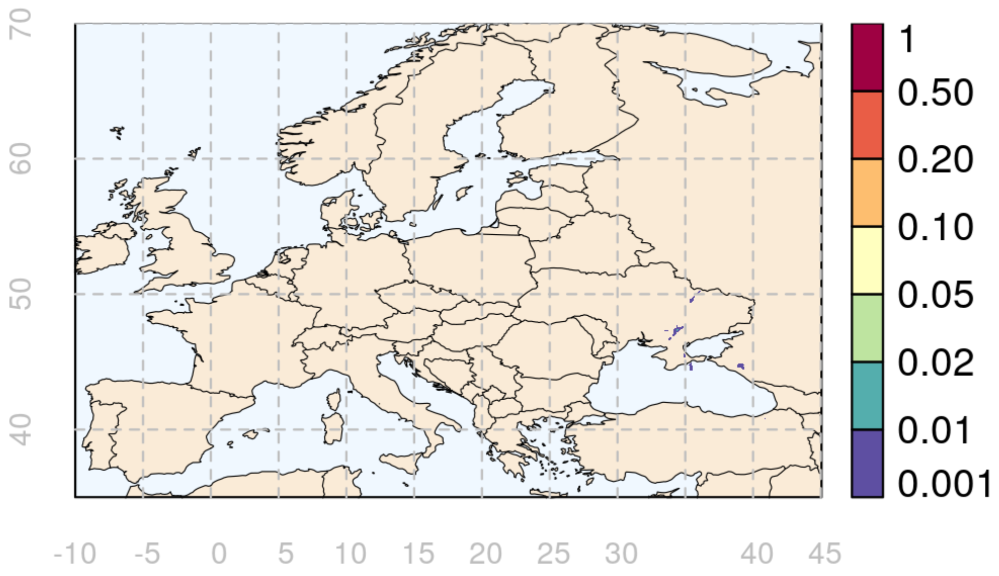
Fictive case!

Rivne NPP
(1 PBq Cs137)

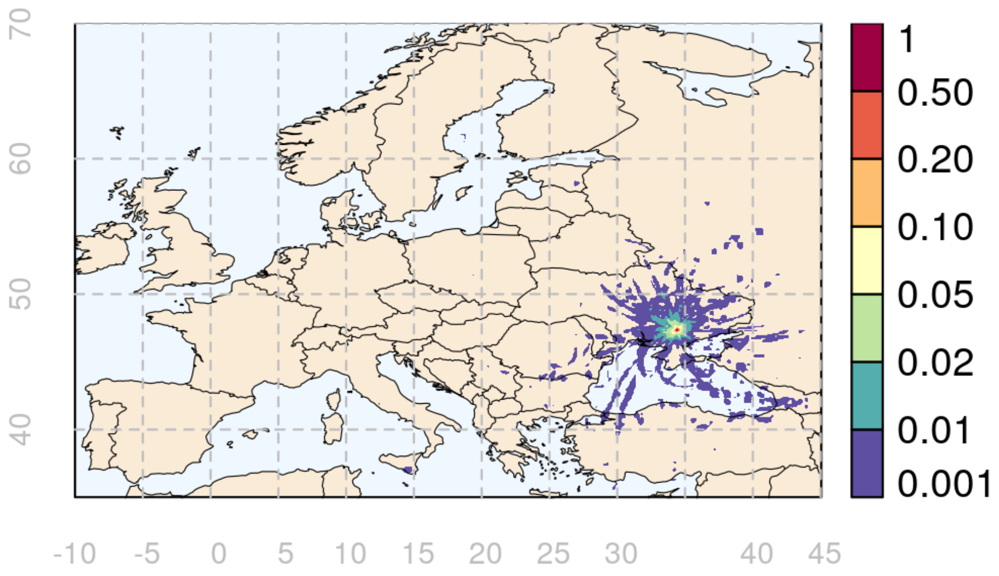


Zaporizhzhia NPP
Cs137

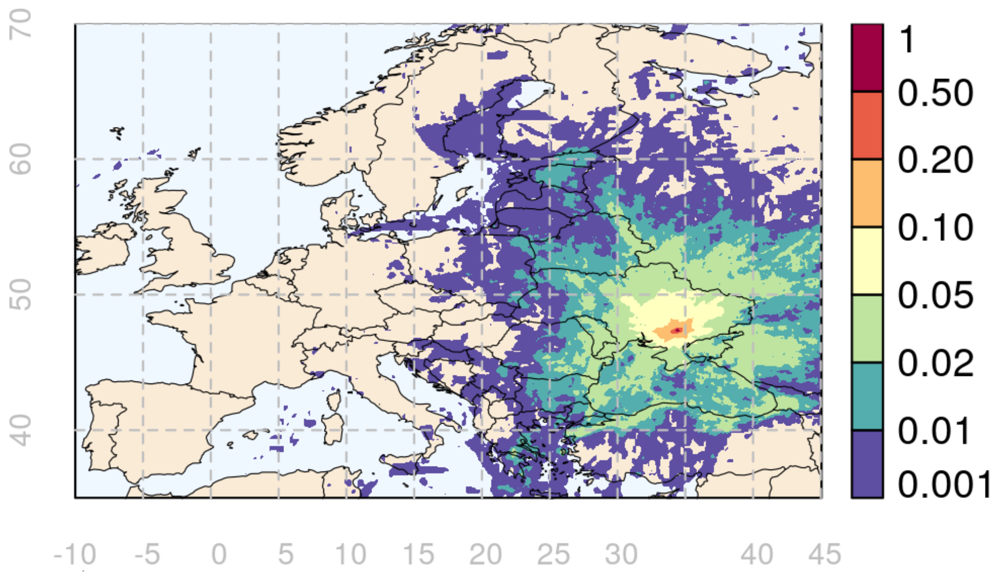
ZNPP - 0.1 PBq - Probability of total deposition > 10kBq/m²



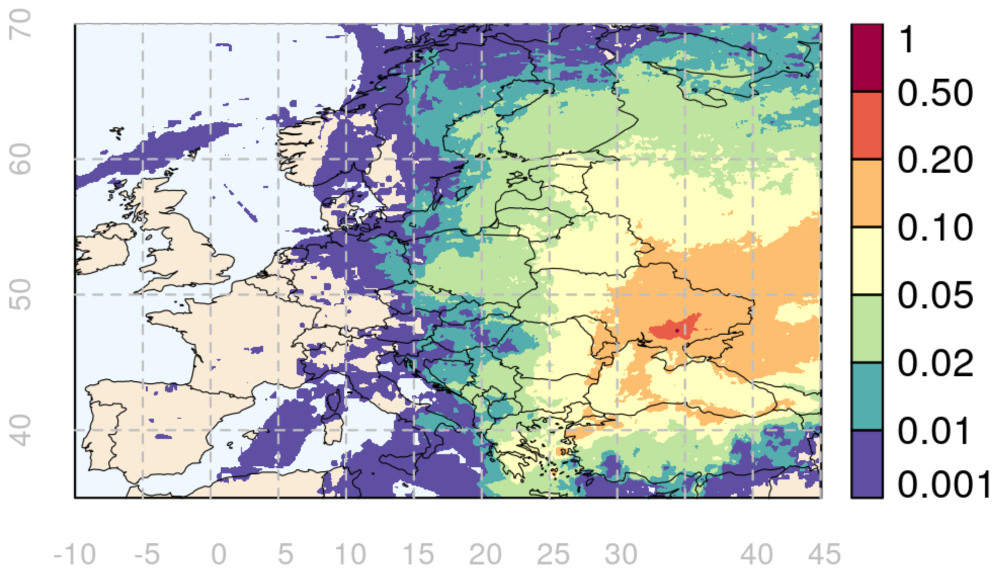
ZNPP - 1 PBq - Probability of total deposition > 10kBq/m²



ZNPP - 10 PBq - Probability of total deposition > 10kBq/m²



ZNPP - 100 PBq - Probability of total deposition > 10kBq/m²



Rivne NPP
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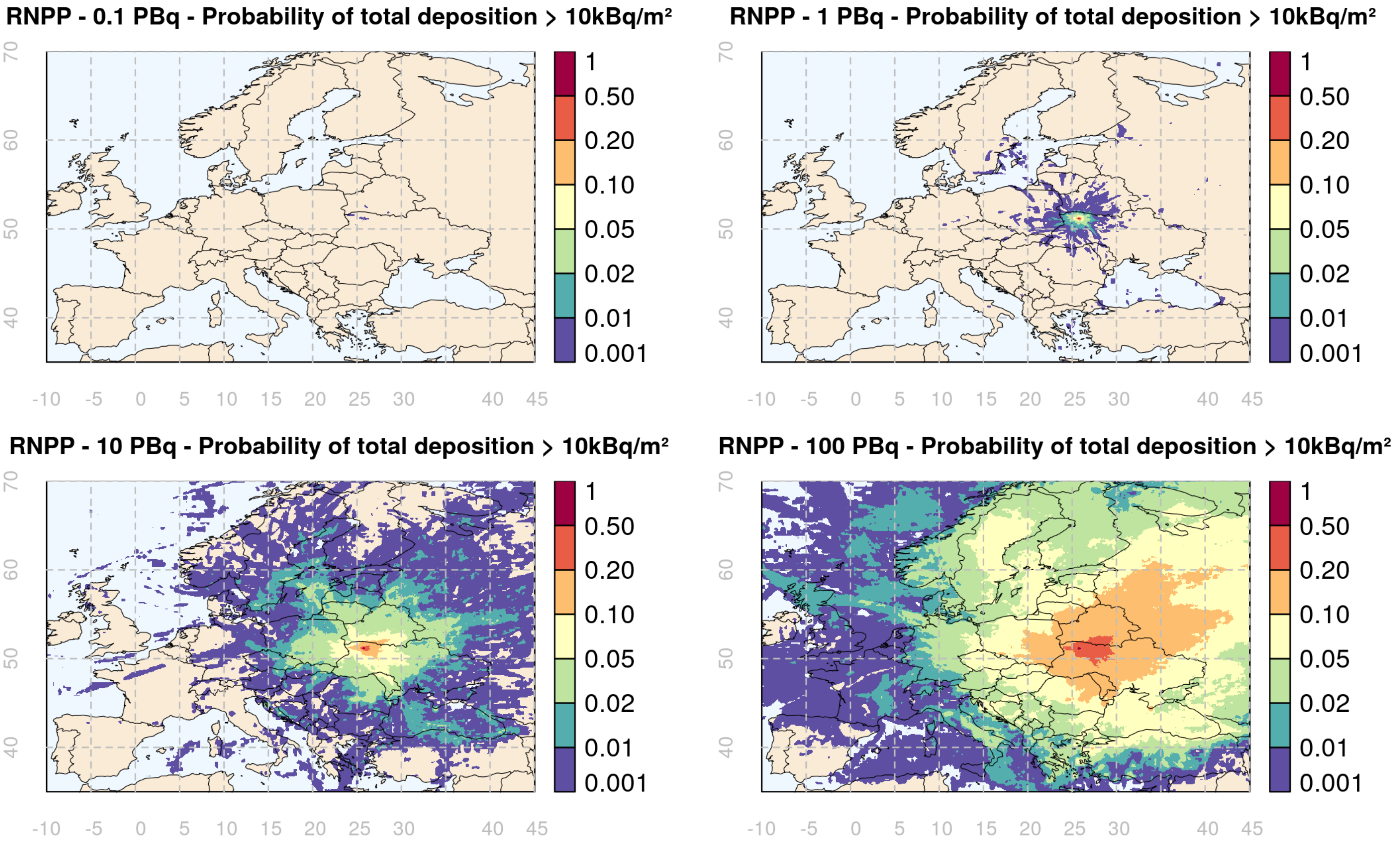
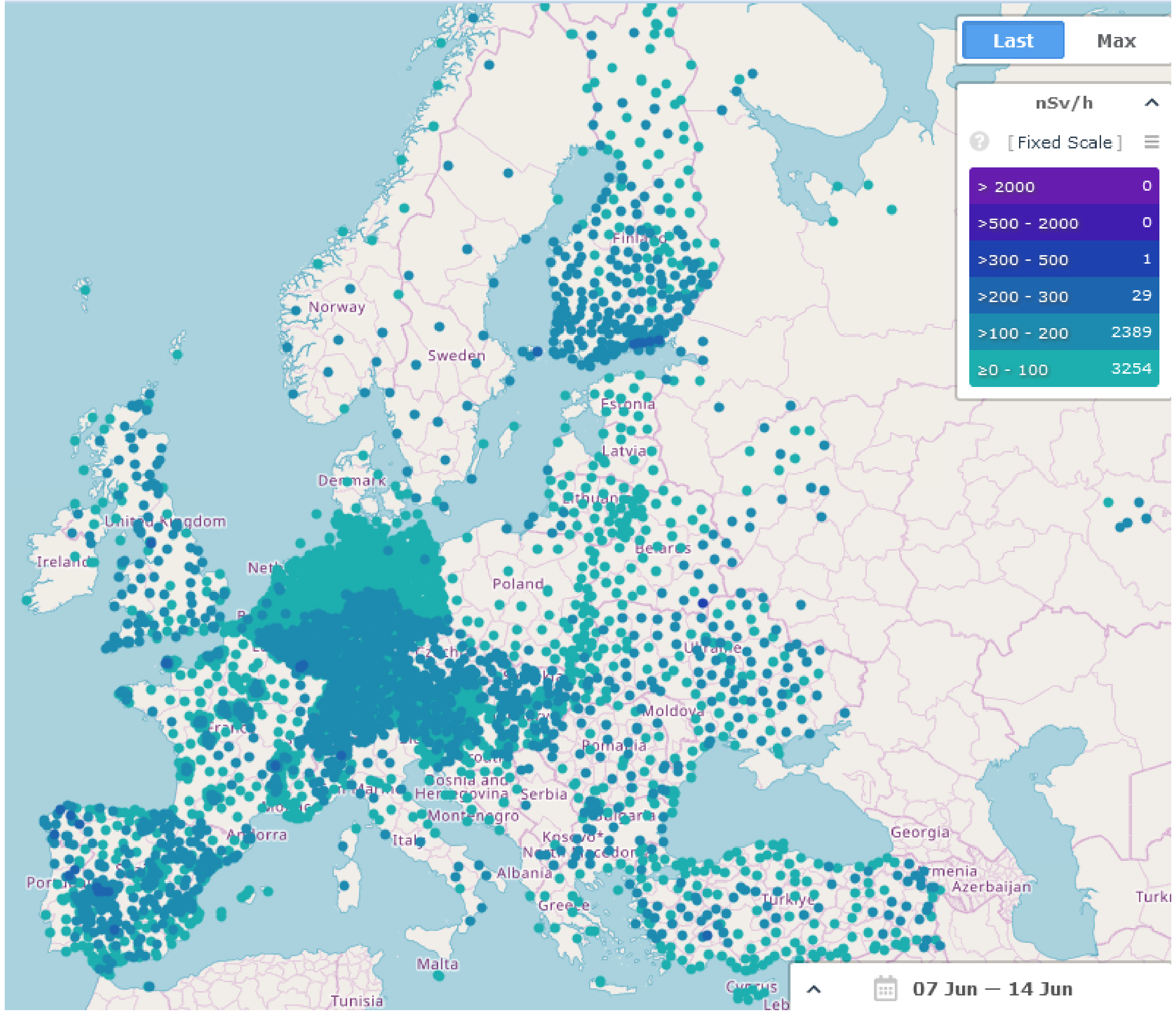
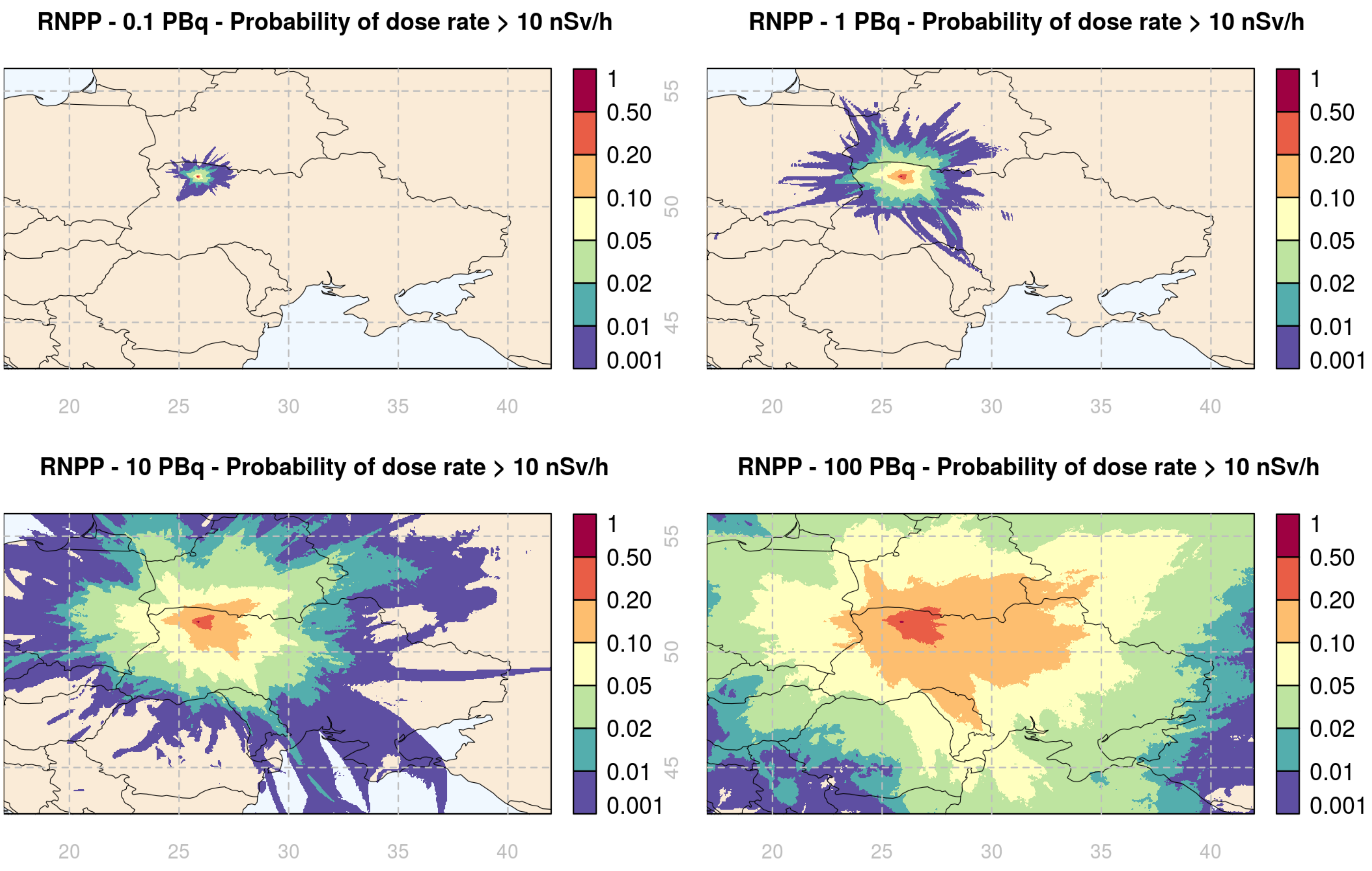


Radiation networks: EURDEP

- EUropean Radiological Data Exchange Platform (EURDEP)
- Approx. 5000 stations
- Ambient dose equivalent rate $\dot{H}^*[10]$
- Cs137: 10 kBq/m^2 → $\dot{H}^*[10]$ = 30 nSv/h



Rivne NPP
Dose rate cloud noble gases (Xe133, Xe135)



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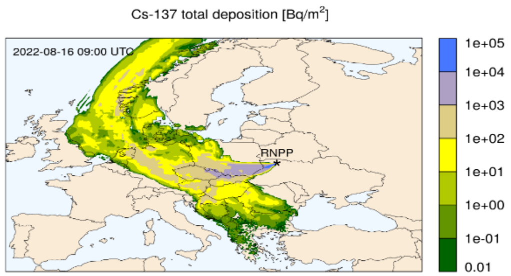

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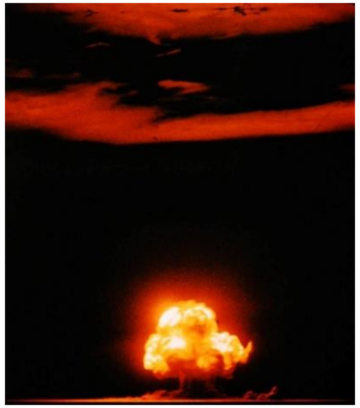
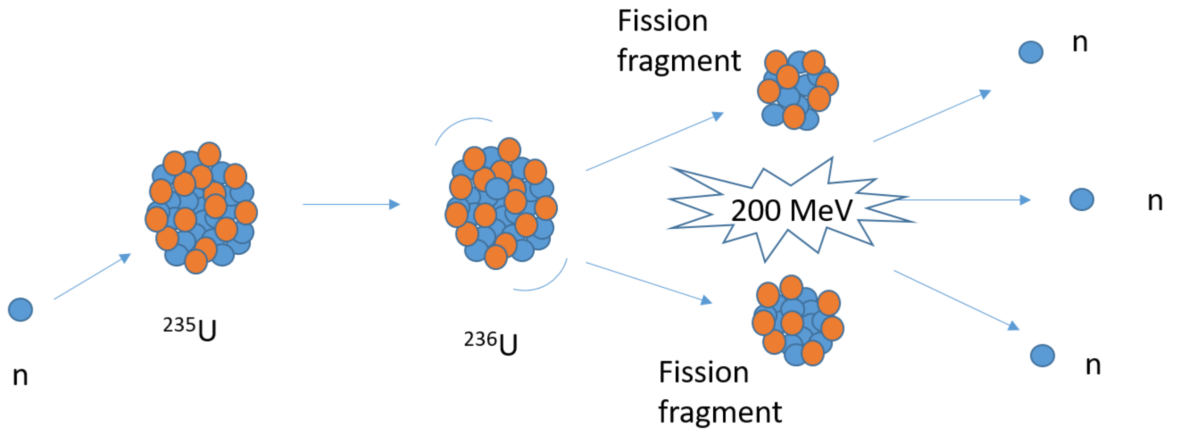
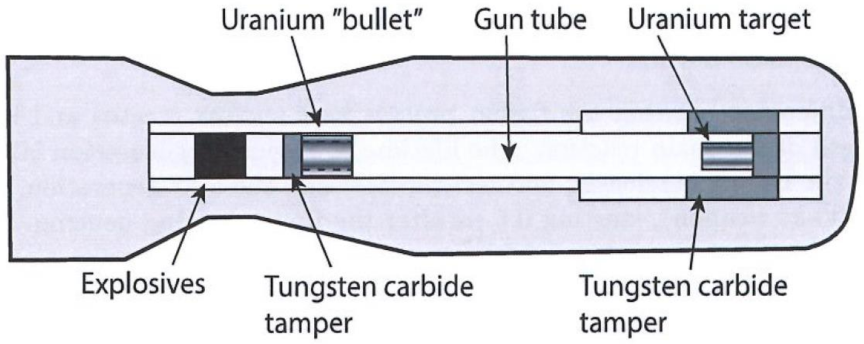
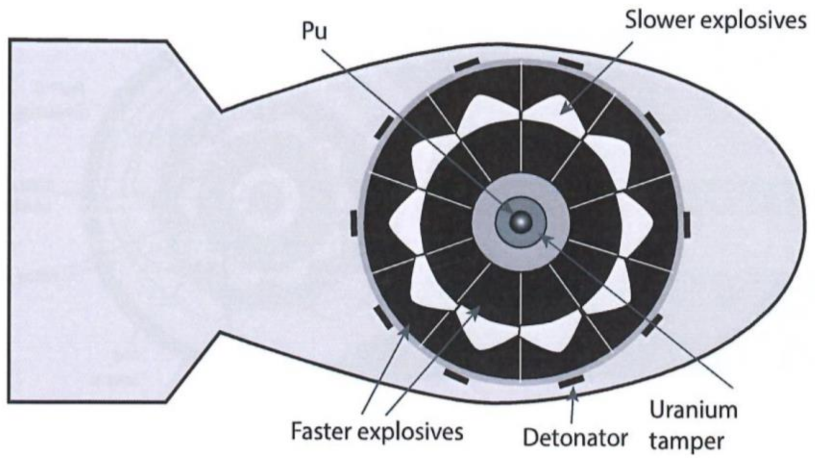


Nuclear Weapons

Fission-based weapons







2 types:

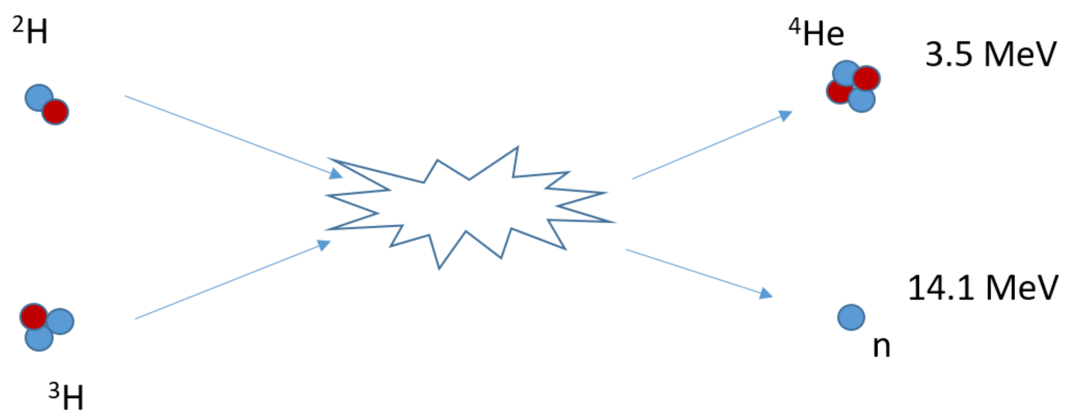
- Gun-type: U-235 – critical mass ()
- Implosion-type: Pu-239 – critical mass()

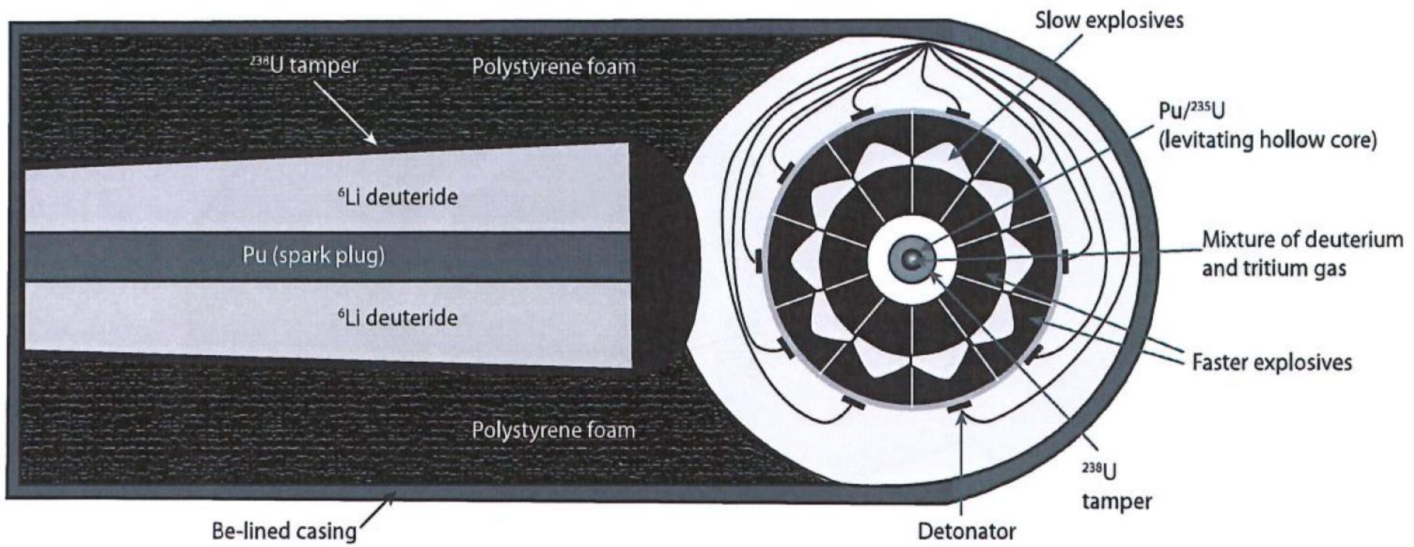
Further possible properties:

- Tamper to increase inertia of fission fuel
- Neutron source ($^{4}He + {}^{9}Be \rightarrow {}^{12}C + n$) to speed-up exponential energy increase (1 shake = 10 ns)
- Boosted: fusion fuel in centre

Nuclear Weapons

Fusion-based weapons (thermonuclear weapons)





→ Reducing last fission stage + neutron transparent: neutron bomb

→ salted bomb: add matearisl with high activation cross section → increase neutron activation

- Boosted fission (^{235}U and ^{239}Pu + ^3H and ^2H)
- ^6Li deuteride as fusion fuel
- $^6Li + n \rightarrow {}^3H + {}^4He$
- X-rays will heat & vaporize polystyrene foam → compression of U-238 tamper
- Fusion, neutrons will add yield via fission Pu spark & U tamper)

→ **Fission-Fusion-Fission**

1 kT = 1000 ton TNT equivalent = $4.2\ 10^{12}$ J = $2.6\ 10^{25}$ MeV

Yield/Russian nuclear forces

Non-nuclear (chemical explosives) ≤ 11 ton TNT

Open literature, e.g.:

- Stockholm International Peace Research Institute
- Nuclear Notebook: How many nuclear weapons does Russia have in 2022?

Pieterjan Huyghebaert

Rusland probeert nieuwe nucleaire langeafstandsraket "Satan 2" uit en raakt testdoel 5.000 kilometer ver

- 4500 nuclear weapons: 1600 operational , 2900 reserve (and 1500 waiting for dismantling);
- Yield: 10 – 800 kT (Highest Yield: Tsar Bomba 50 MT)
- Vectors - the nuclear triad: short range to *intercontinental ballistic missiles* (ICBM) - *submarine launched ballistic missile* (SLBM) and aircrafts with nuclear capability

Nuclear Notebook: How many nuclear weapons does Russia have in 2022? (Feb 2022)

Table 1. Russian nuclear forces, 2022

Type/name	Russian designation	Launchers	Year deployed	Warheads x yield (kilotons)	Total warheads
Strategic offensive weapons					
ICBMs					
SS-18 M6 Satan	RS-20V	40	1988	10 x 500/800 (MIRV)	400[1]
SS-19 M3 Stiletto	RS-18 (UR-100NUTTH)	0	1980	6 x 400 (MIRV)	0[2]
SS-19 M4	? (Avangard)	6	2019	1 x HGV	6
SS-25 Sickle	RS-12M (Topol)	9[3]	1988	1 x 800	9
SS-27 Mod 1 (mobile)	RS-12M1 (Topol-M)	18	2006	1 x 800?	18
SS-27 Mod 1 (silo)	RS-12M2 (Topol-M)	60	1997	1 x 800	60
SS-27 Mod 2 (mobile)	RS-24 (Yars)	153	2010	4 x 100? (MIRV)	612[4]
SS-27 Mod 2 (silo)	RS-24 (Yars)	20	2014	4 x 100? (MIRV)	80
SS-X-29 (silo)	RS-28 (Sarmat)	–	(2022)	10 x 500? (MIRV)	–
Subtotal		**306**			**1,185[5]**
SLBMs					
SS-N-18 M1 Stingray	RSM-50	0/0	1978	3 x 50 (MIRV)	0[6]
SS-N-23 M2/3	RSM-54 (Sineva/Layner)[7]	5/80	2007	4 x 100 (MIRV)	320[8]
SS-N-32	RSM-56 (Bulava)	5/80	2014	6 x 100 (MIRV)	480[9]
Subtotal		**10/160[10]**			**800[11]**
Bombers/weapons					
Bear-H6/16	Tu-95MS6/MS16/MSM	55	1984/2015	6-16 x AS-15A ALCMs or 14 x AS-23B ALC	448
Blackjack	Tu-160/M	13	1987/2021	12 x AS-15B ALCMs or AS-23B ALCM, bombs	132
Subtotal		**68[12]**			**580[13]**
Subtotal strategic offensive forces		**534[14]**			**2,565[15]**

Non strategic and defensive …

Characteristics nuclear explosions

- Important differences depending on location explosion
- Differences in radioactive particle size distribution: important for fall-out
- Highest potential impact for humans: near surface explosion (at some altitude above ground)

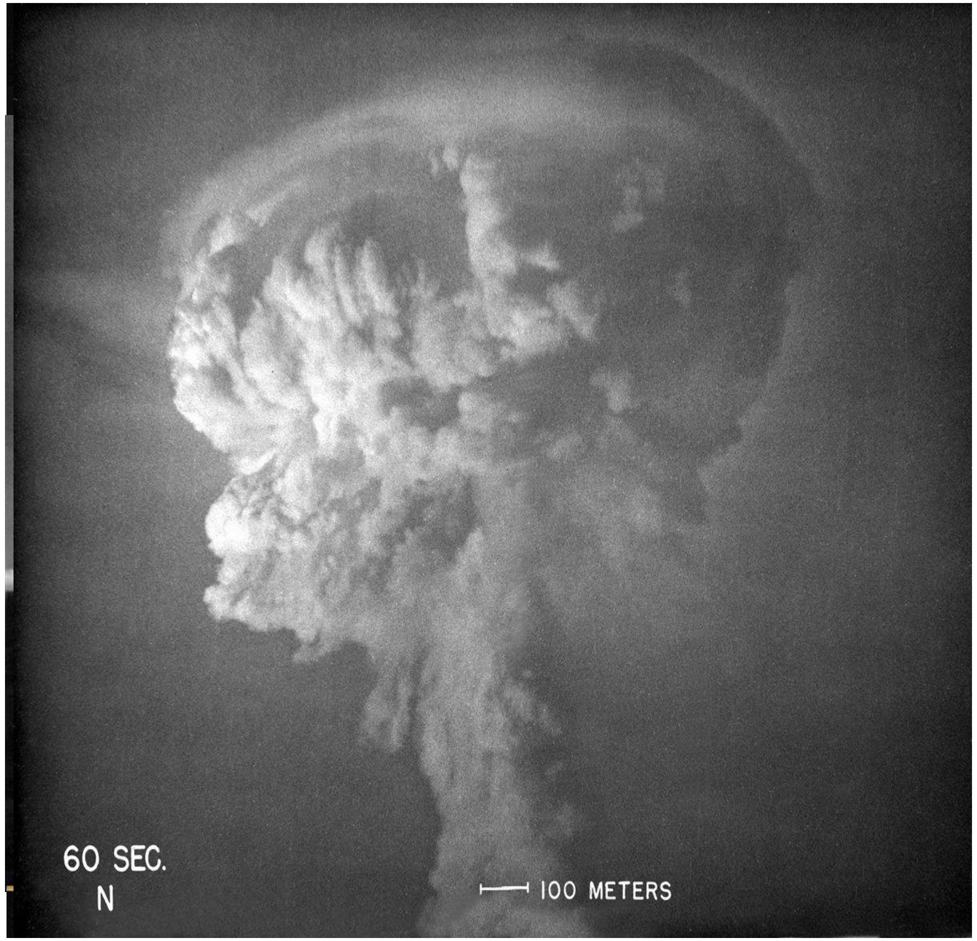
Near surface

High altitude

Underground

Underwater

Effects of a nuclear blast



- Fireball
  - Many times more brilliant than the sun → blindness
  - In <1 sec: max. diameter of 840 m diameter (50 kT)
  - In 1 minute: cooled down → doesn't glow anymore
- Mushroom cloud: debris-filled + radioactivity (fission fragments and activation products)

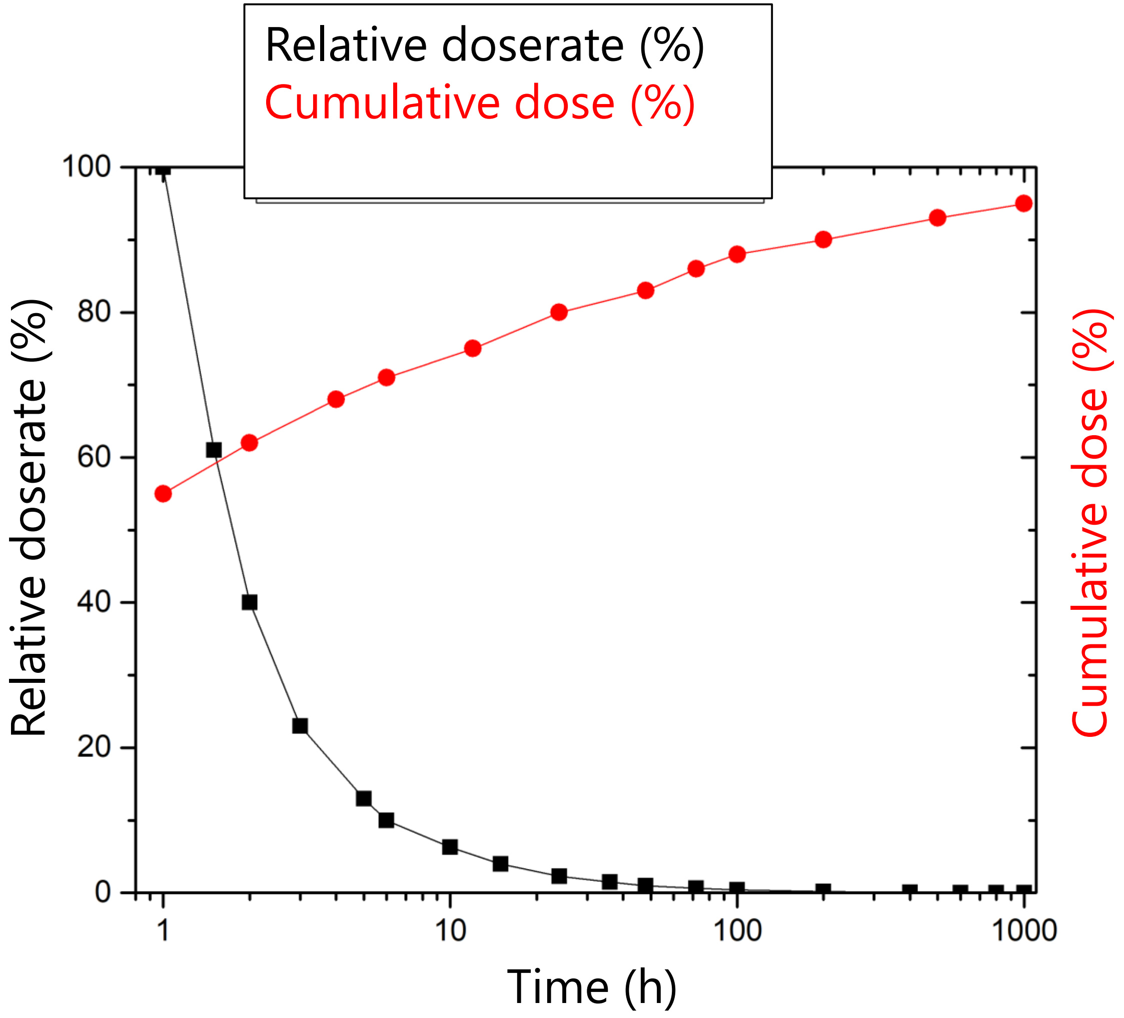
Energy partitioned as follows:

- 50% Blast and ground shock
- 35% Thermal Radiation
- 15% Ionizing Radiation
  - 5% Prompt (first minute) → prompt radiation effects and electromagnetic pulse (EMP)
  - 10% Delayed (minutes to years) → fallout

Effects of a nuclear explosion

Fallout

- Large amount of fission & activation products
  - Highest activities of short-lived radionuclides
  - Fusion weapon: 40% less fission products compared with 100% fission weapon
  - Radioiodine's (I-131, I-133, …): up to 20% of total activity in cloud
  - Particle size can be from mm to < µm
    - Effect on deposition and respirable fraction
    - Ground shine of fallout dominant



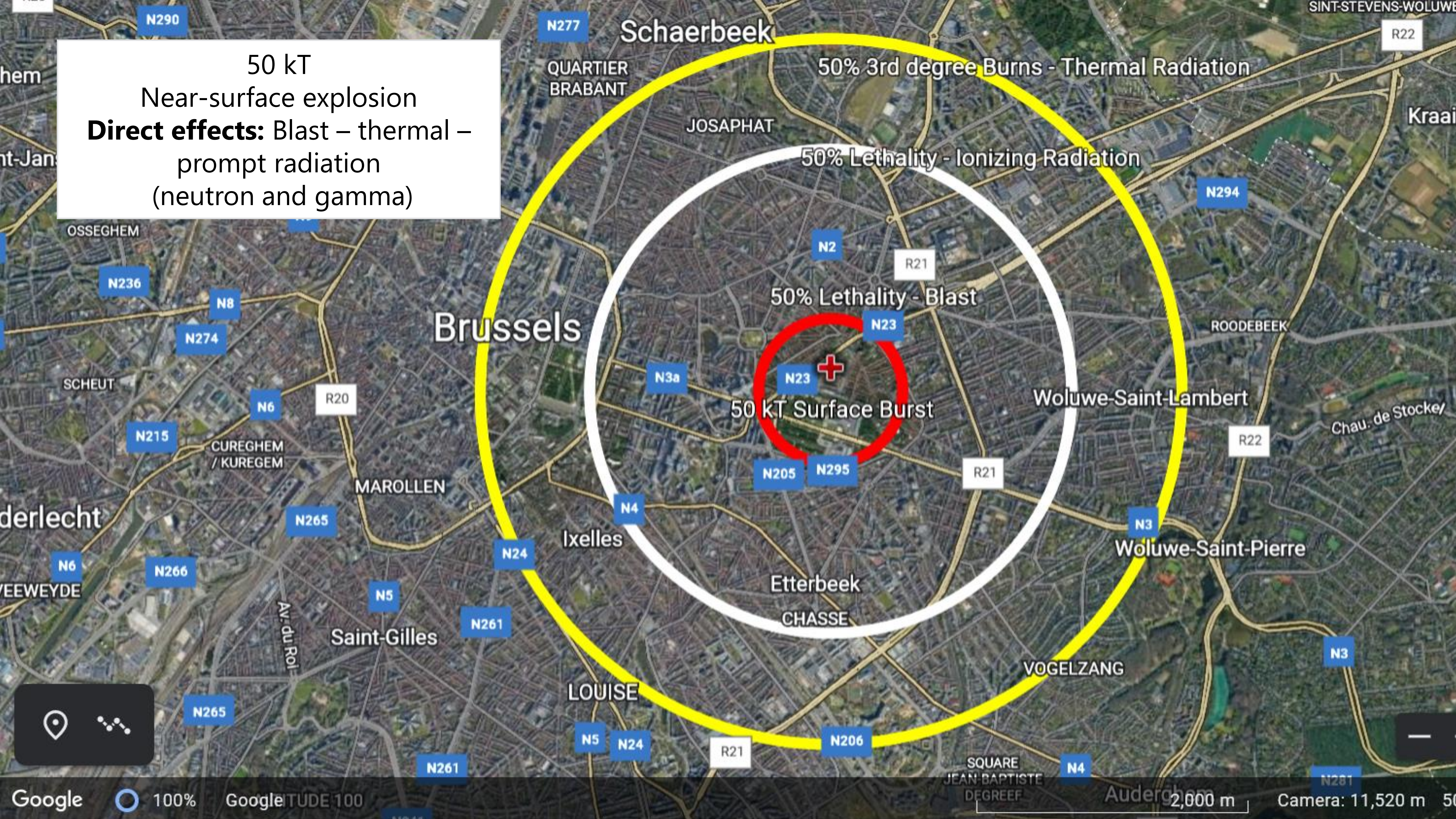
Based on Glasstone & Dolan

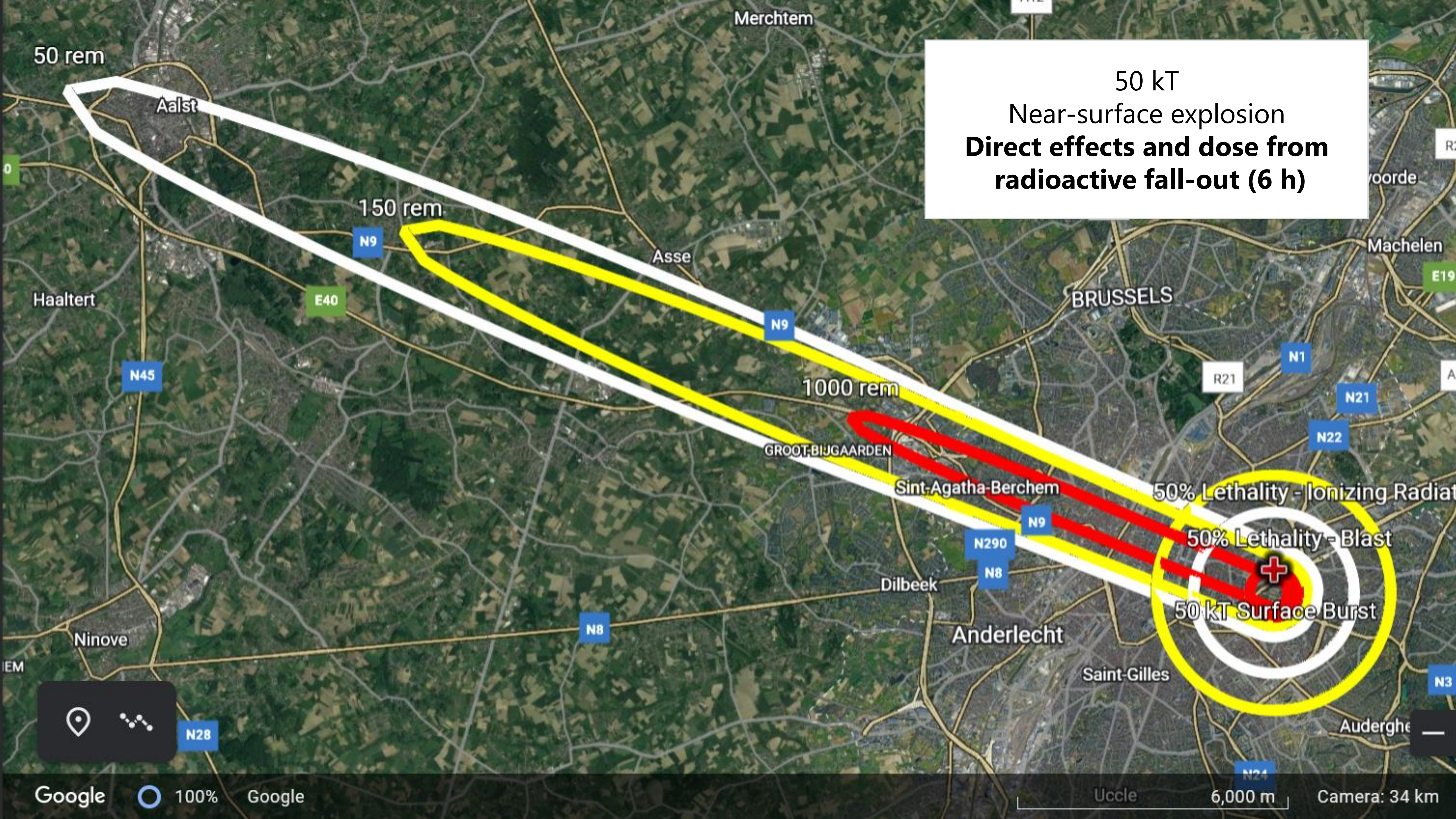
Impact calculations

Hotspot – Fast assessment tool by Lawrence Livermore National Laboratory (version 3.0)

- Based on work of Glasstone & Dolan (Glasstone, S, and Dolan, P J. *The Effects of Nuclear Weapons. Third edition*. United States: N. p., 1977. Web. doi:10.2172/6852629)
- 100% fission weapon assumed (fusion weapon: fall out "only" ~40%)
- Near-surface explosion at Brussels
- Both direct effects and fall-out calculations
- Fall-out: typical Belgian meteo-conditions (no rain, 3.5 m/s wind speed)

50 kT
Near-surface explosion
Direct effects: Blast – thermal – prompt radiation
(neutron and gamma)

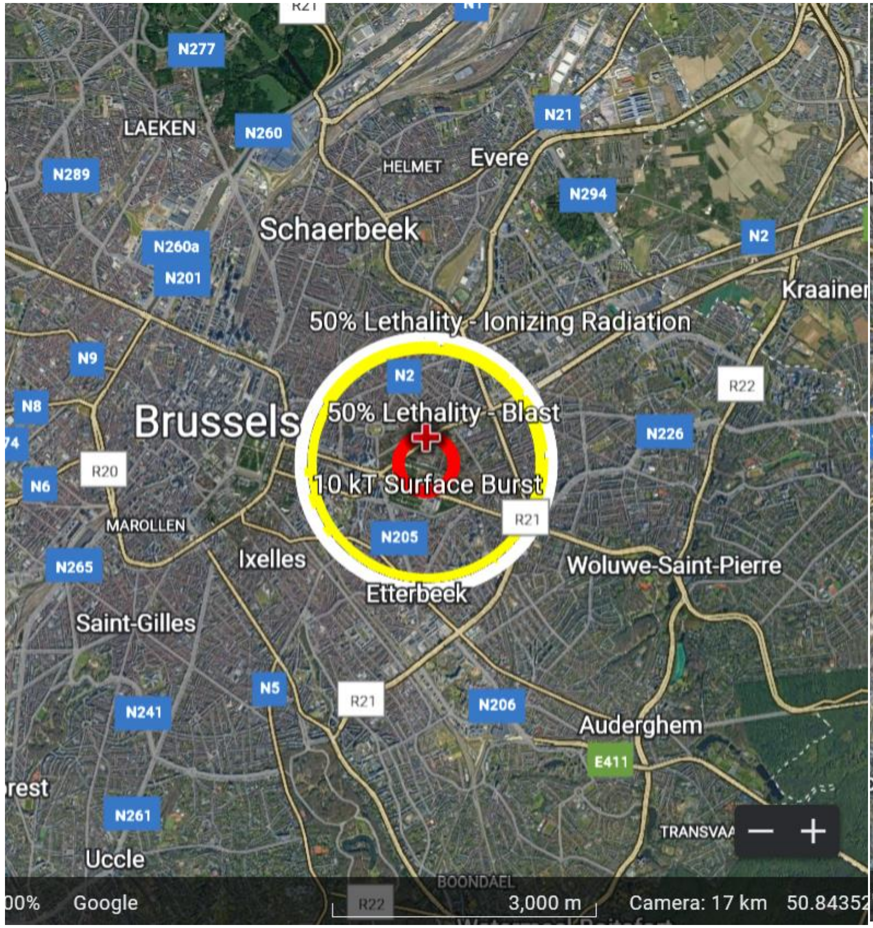




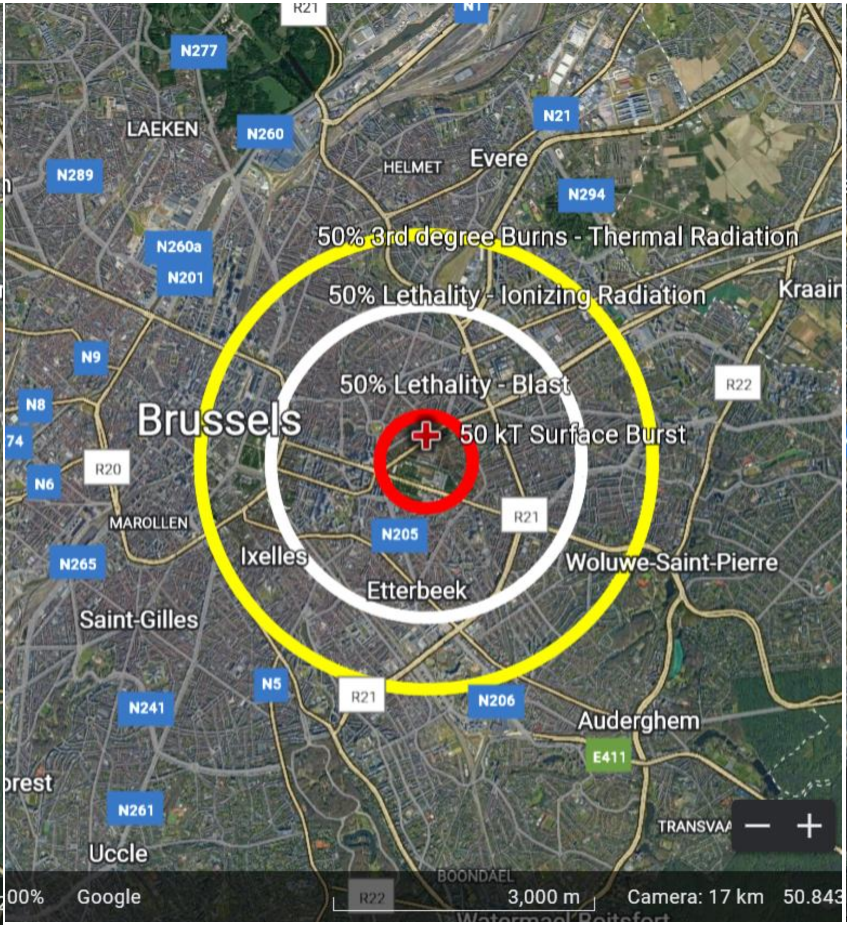
50 kT
Near-surface explosion
Direct effects and dose from radioactive fall-out (6 h)
50 rem
150 rem
1000 rem
50% Lethality - Ionizing Radiat
50% Lethality - Blast
50 kT Surface Burst
Merchtem
Aalst
Asse
Haaltert
BRUSSELS
Machelen
GROOT-BIJGAARDEN
Sint-Agatha-Berchem
Dilbeek
Anderlecht
Saint-Gilles
Ninove
N9
E40
N45
N1
R21
N21
N22
E19
N290
N8
N3
N28
Google
100%
Google
Uccle
6,000 m
Camera: 34 km

Direct effects as a function of yield:

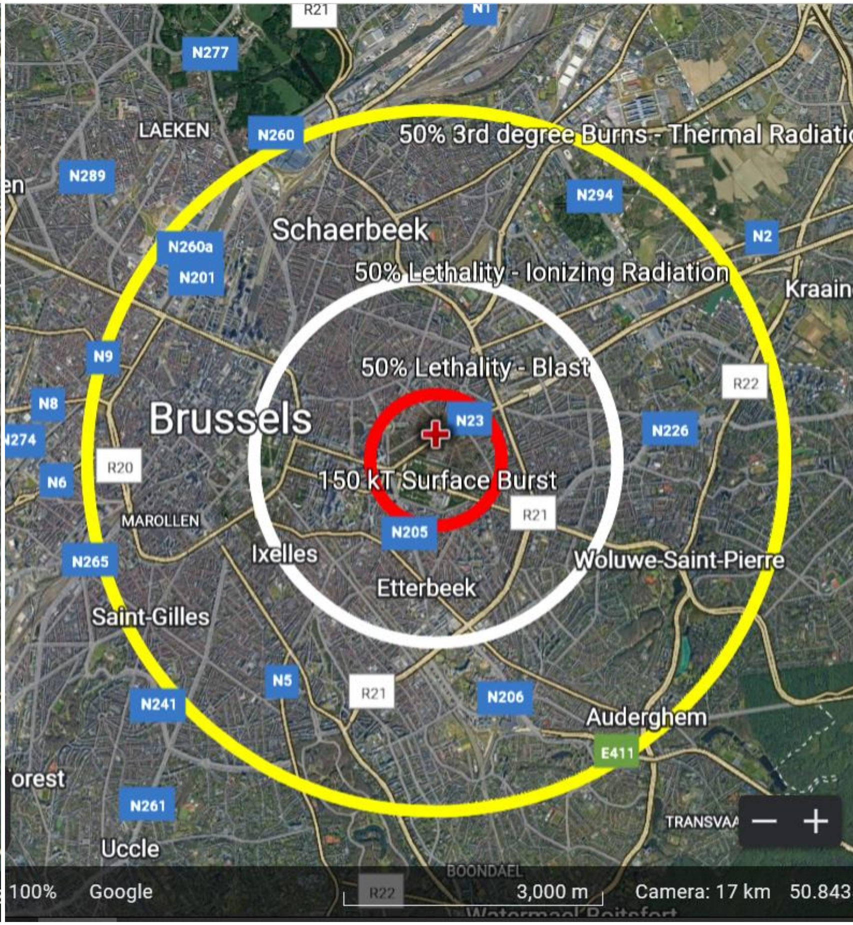
10 kT



50 kT



150 kT

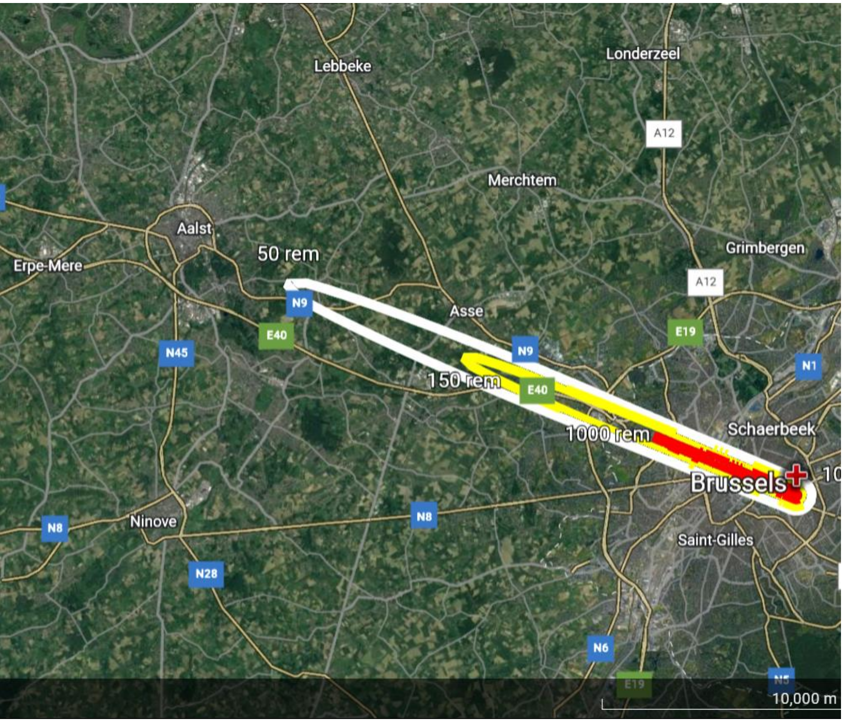


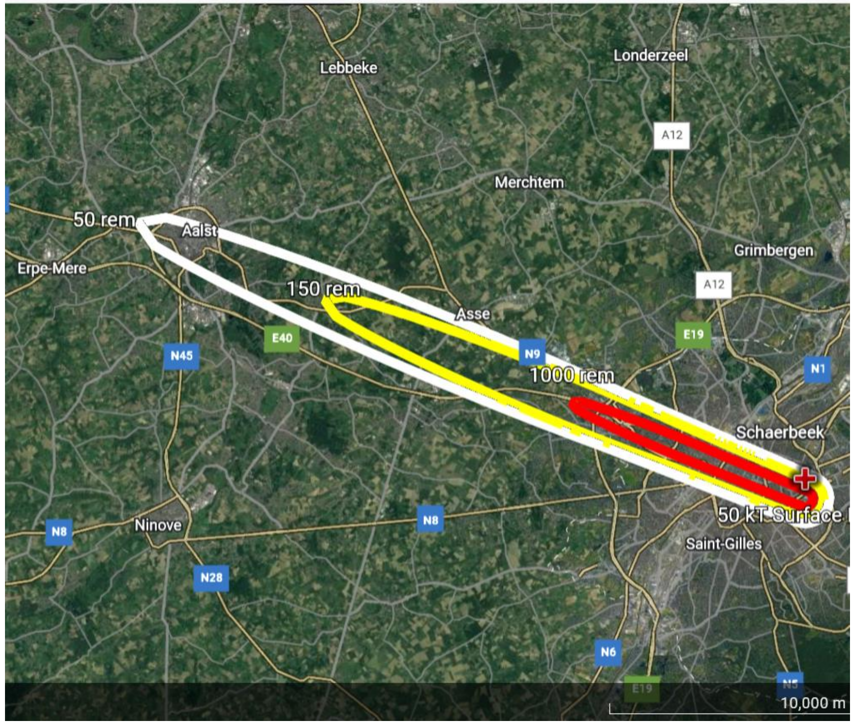
Fall-out as a function of yield:

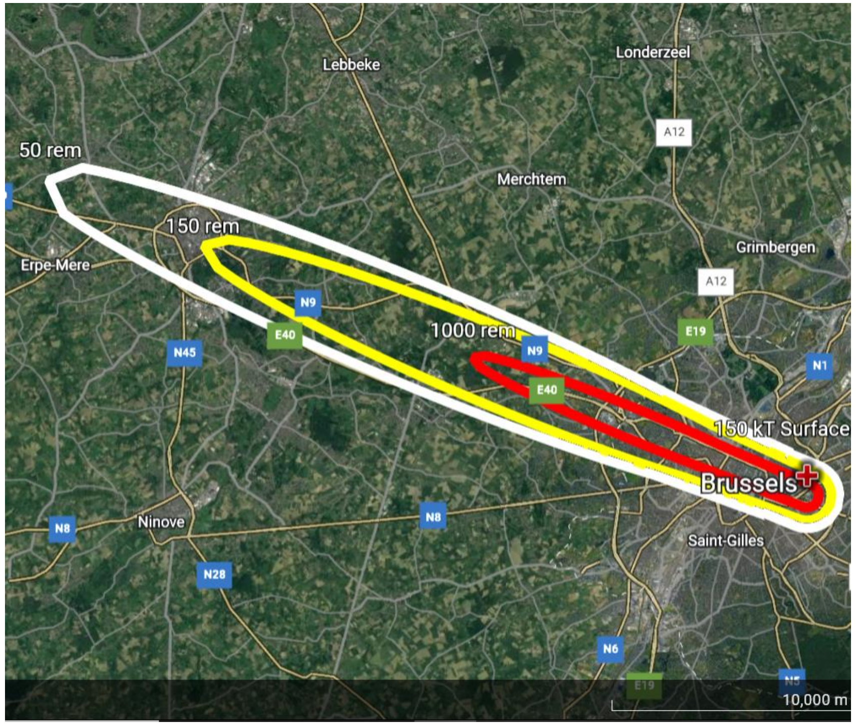
10 kT

50 kT

150 kT

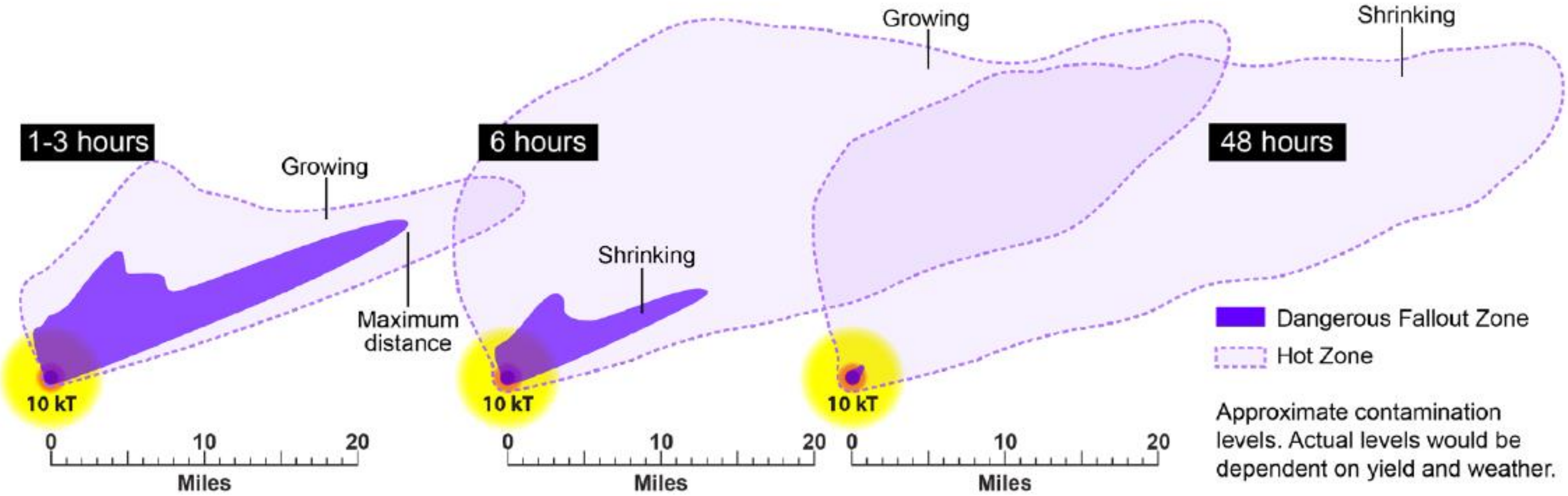






Reality would look more like this

Total dose (previous slides) versus change in fall-out contamination, (dose rate)



From: Rapid Radiological/Nuclear Consequence Assessment Tools, LLNL-TR-682, 2015

Potential victims

50 kT, Brussels (Stat-Bel)

Location	Brussels	
	50 kT	
Type	r (km)	Population impacted
Blast - 100% lethality	0.45	198
Blast - 50% lethality	0.53	304
Blast - threshold shattered glass injury	6.99	755.155
Thermal - 3rd degree	2.61	70.808
Prompt - 95% lethal, weeks	1.71	20.739
Prompt - 50% lethal, weeks	1.79	24.278
	area (km^2) - 6h	Population Impacted
Fallout - 10 Sv (lethal)	6.7	7.600
Fallout - 4 Sv (50% lethal)	15	15.000
Fallout - 1 Sv	47	37.500

What if Russia would use a nuclear weapon in Ukraine?

Is there an impact on Western Europe?

ElectroMagnetic Pulse (EMP): cf. Starfish Prime test (8 July 1962) – High altitude test (400 km) - Damage 1445 km from explosion

Fallout:

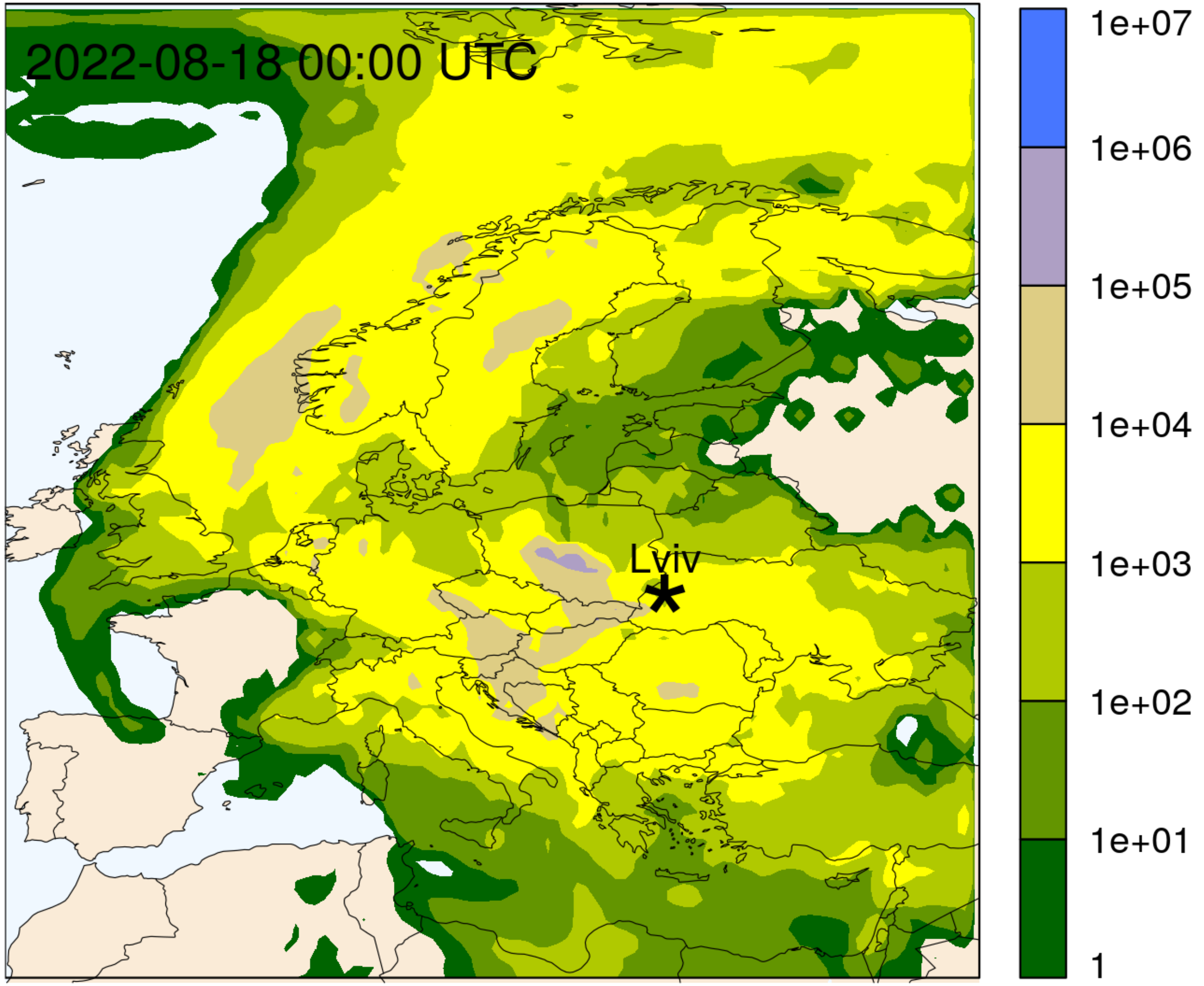
- meteorological conditions, particle distribution, yield …
- Experience from nuclear testing:
  - Rain-out of radioactivity in Tahiti at 1200 km distance from test-site (Mururoa -French Polynesia) 17 July 1974
    - Dose to population: 0.8 mSv
    - Contamination levels would require food countermeasures today in Europe (trade)
- Modelling (Flexpart with numerical weather data, ECMWF)
  - Meteo conditions: case of 12 August 2022
  - Height distribution of radioactivity
  - Particle size

Case study
Fictive!

Explosion of
50 kT

I131 deposition
Particle size:
- **0,6 µm**
- 6 µm
- 60 µm

Fixed height



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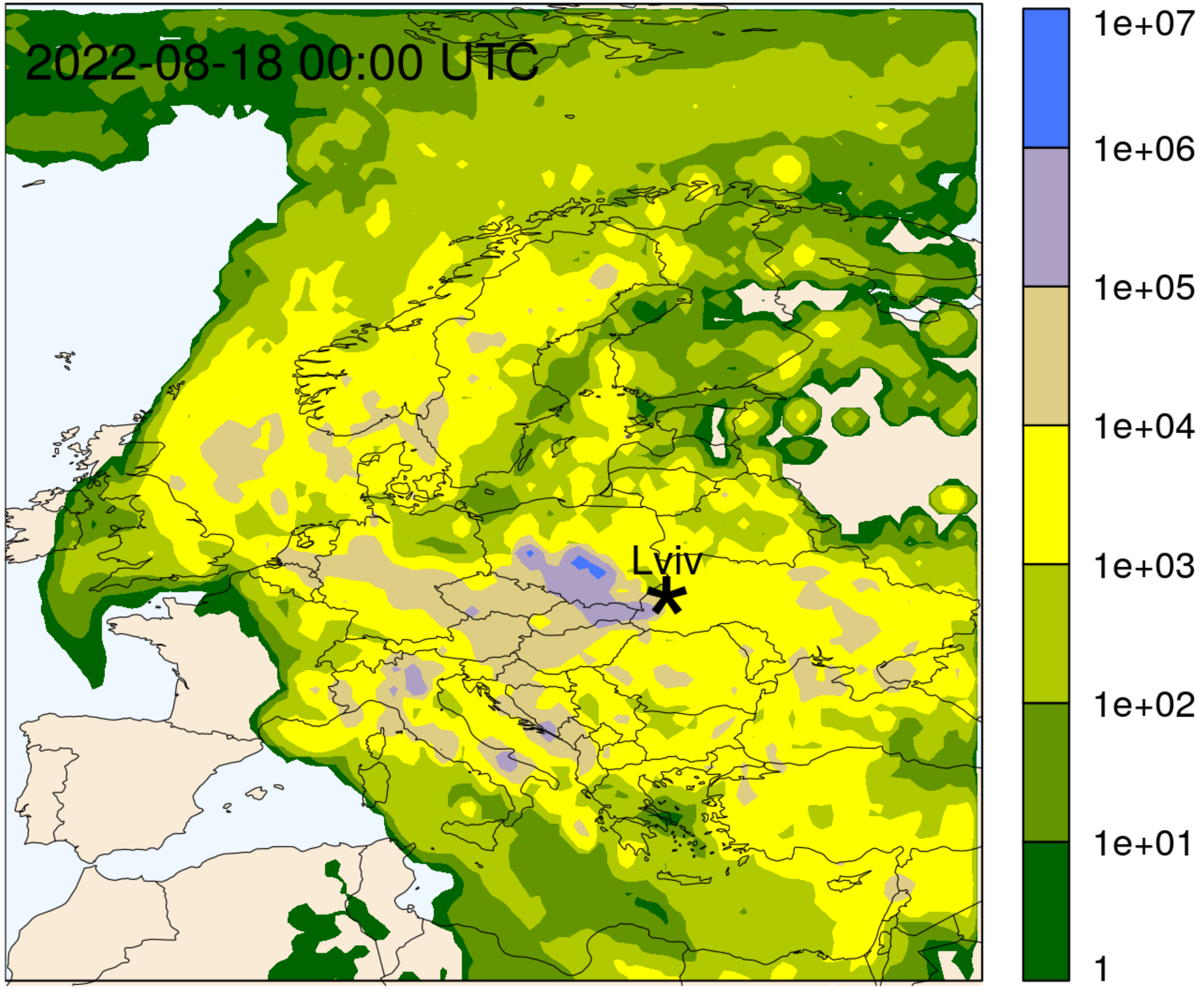

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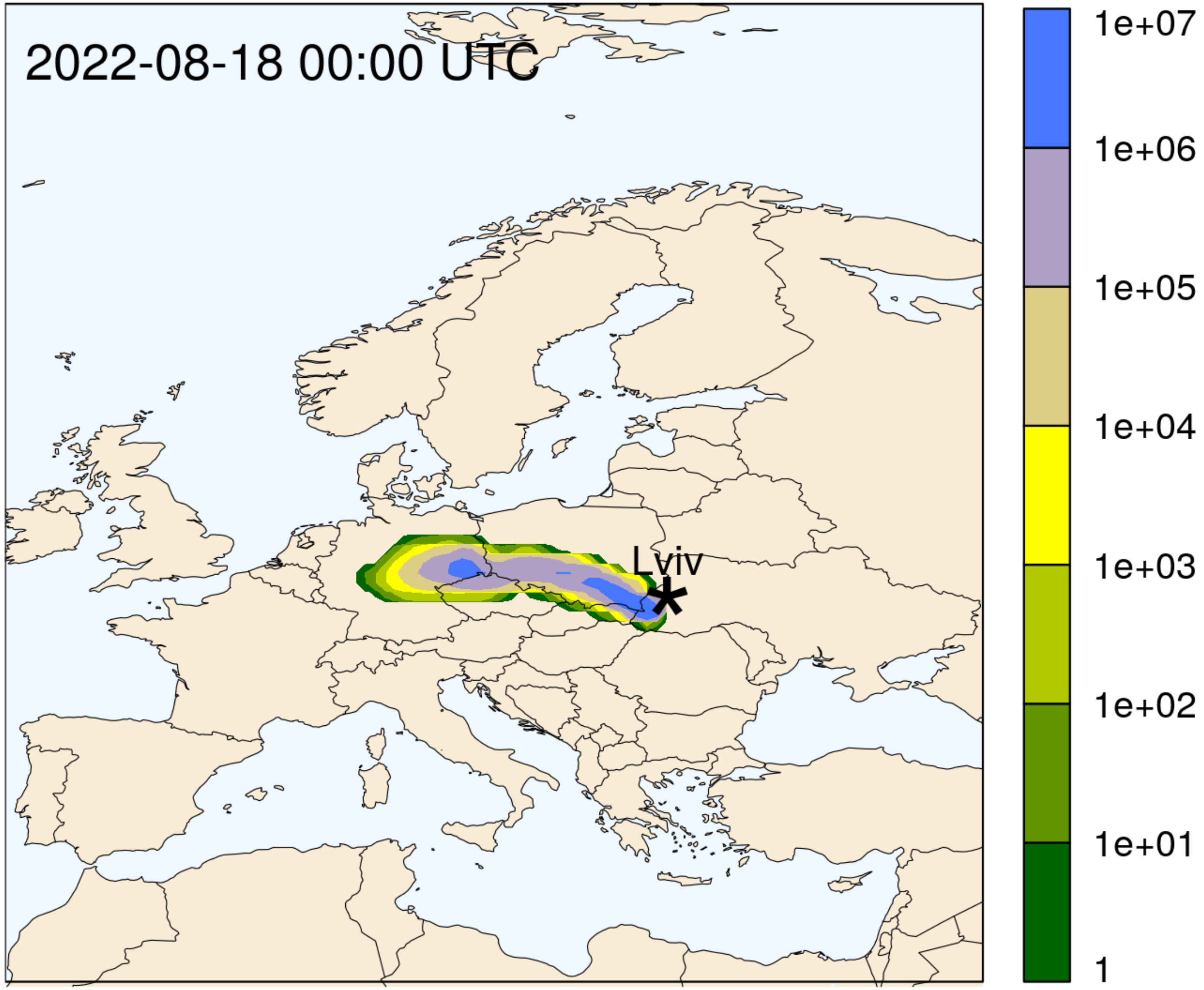

Questions?