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Risk Sciences

Consequences of a Large Release of Cesium 137 from Nuclear Power Plant Zaporizhzhia

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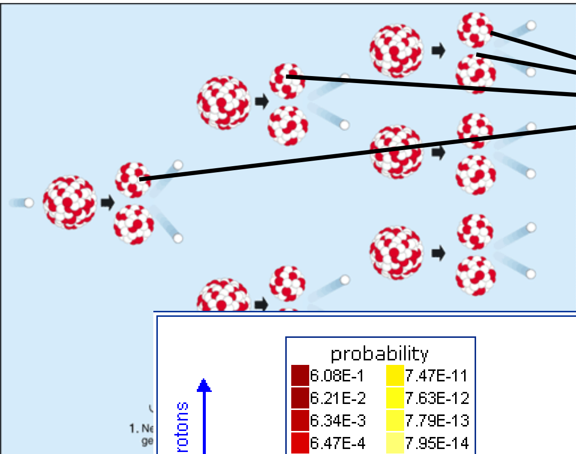
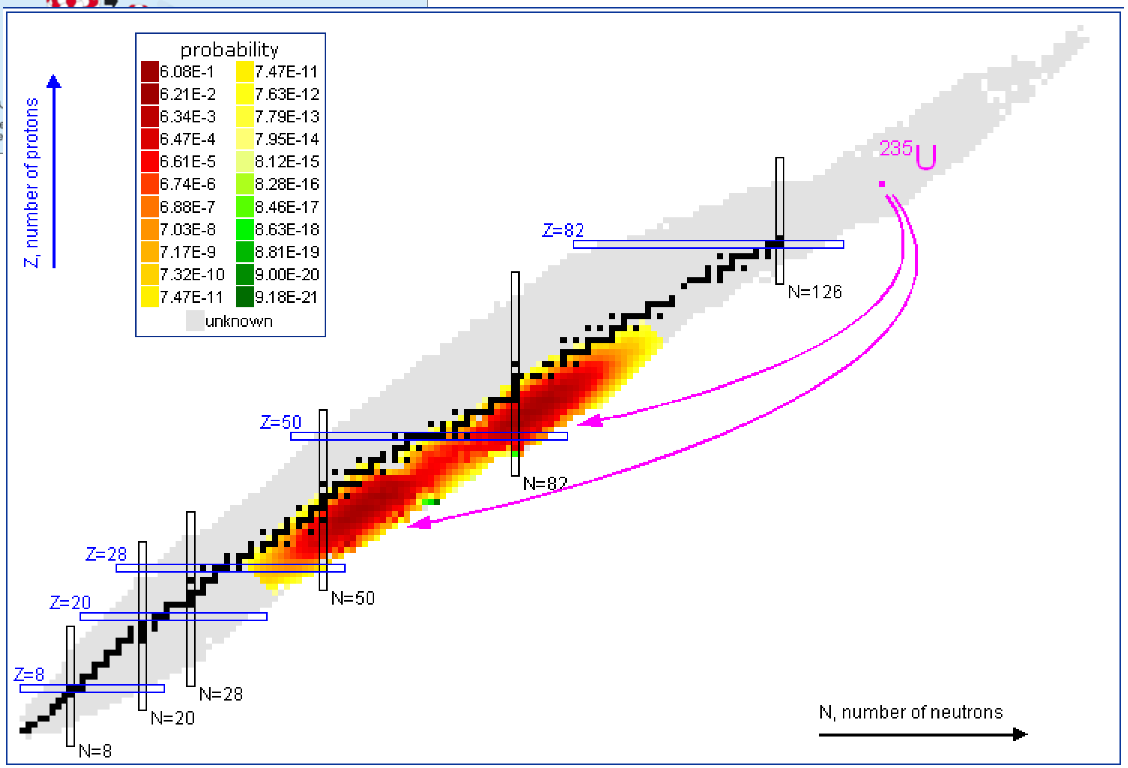
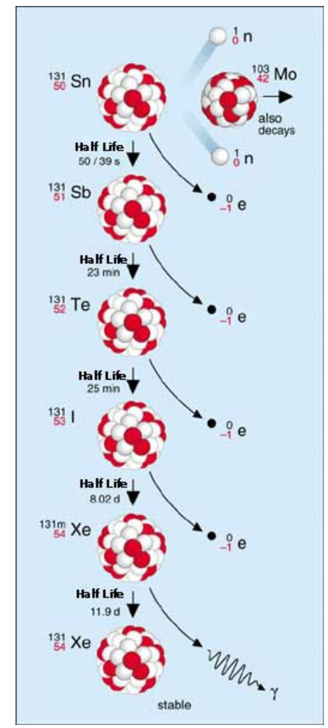
Source of risk – reactor core inventory



Fission products



Decay chains



Key Radioisotopes

- Noble Gases – Krypton, Xenon
  - e.g. Kr-87, half life ~2h, Xe-133, half life ~5d
- Iodine
  - e.g. I-131, half life ~8d
- Cesium, Strontium
  - e.g. Cs-137 half life ~30y
- Early phase – noble gases and Iodine
- Late phase - Cesium (focus of this analysis)

Risk Considerations

- Distinguish two different warlike impacts on the plant:
  - Military attack to destroy the nuclear power plant.
  - Military attack to control the nuclear power plant site.

- In the first case, suitable munitions would be selected to reach the target - bunker-busting weapons, suitable bombs or guided missiles.

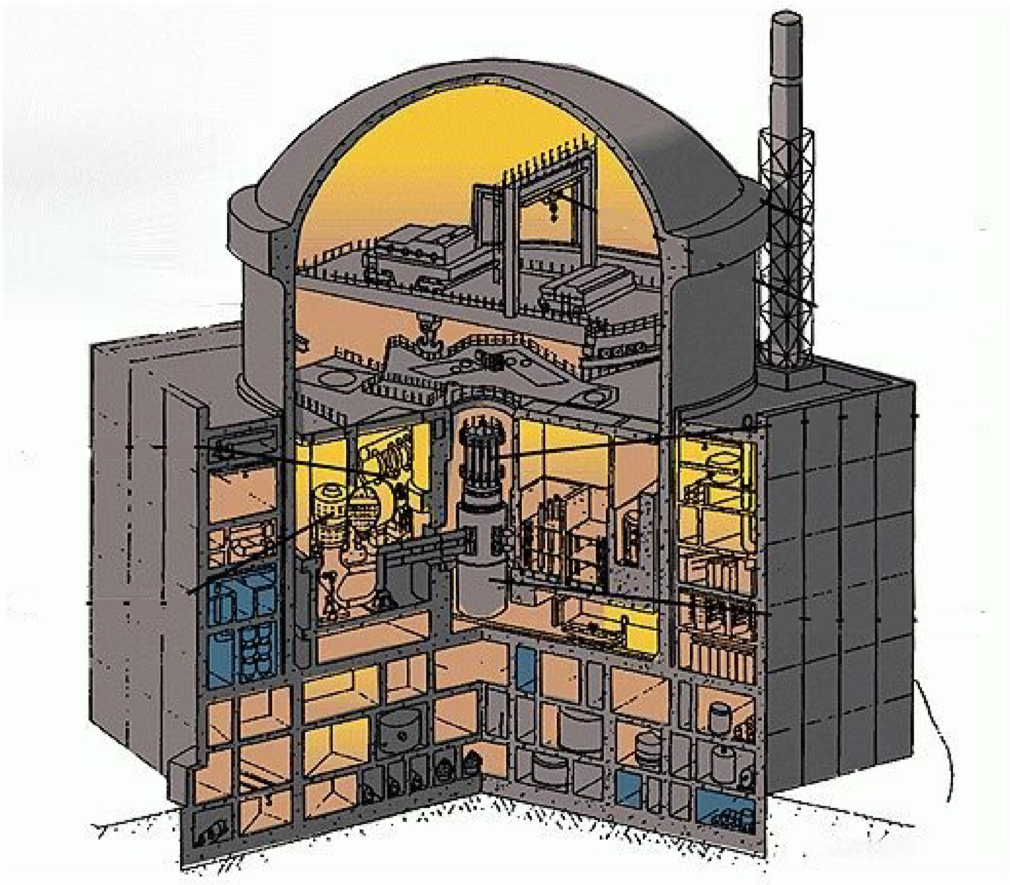
- In this case, destruction of the facility and substantial releases must be assumed. However, this scenario is not very likely, since no advantage for warring parties is apparent.

Risk Considerations

- More likely scenario -> Combat operations to control power plant or fight to combat units at the power plant site.
- Weapons used are therefore not aimed at destroying civil structures of the plant, but at fighting troops. Depending on the accuracy of the hits, however, damage to the plant may still occur.
- It can be assumed that such hits will not destroy plant components that are bunkered for "civilian" reasons or designed to withstand aircraft crashes (e.g. containment). Penetration of the containment might occur without destroying the whole structure
- However, other plant components (e.g. power lines, buildings not specially reinforced) could be destroyed.

Introduction - VVER1000

- **VVER1000 –** Водо-водяной энергетический реактор

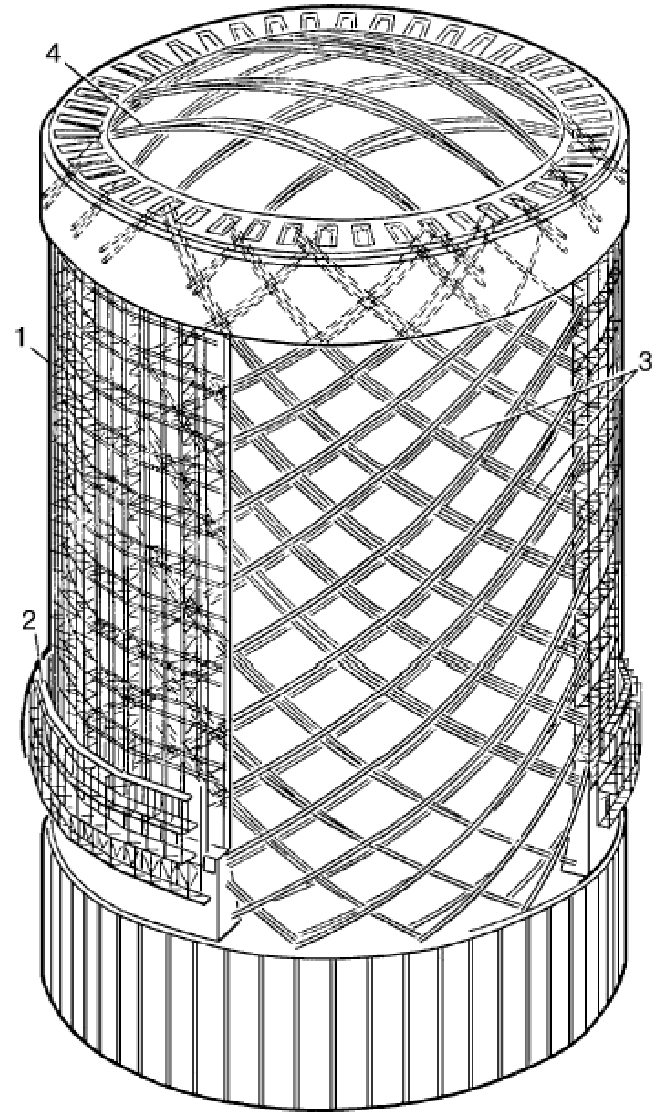


- **Water cooled**
- **Water moderated**
- **Electrical power 1000MW**
- **Thermal power 3000MW**

VVER-1000. Containment

- Concrete cylinder
- Reinforced by pre-stressed wire bundles

1. Cage of reinforcement
2. Boxing for concrete formation
3, 4. Reinforcing wiring



The reactor building construction is designed also to withstand effects of an external air blast with intensity 0.3 kgf/cm 2 for 1s. The containment structure must withstand the impact of a falling plane with speed of 750 km/h and mass 10 t.

Internal diameter	45 m
Height	66 m
Wall thickness	1.2 m
Base plate thickness	2.4 m

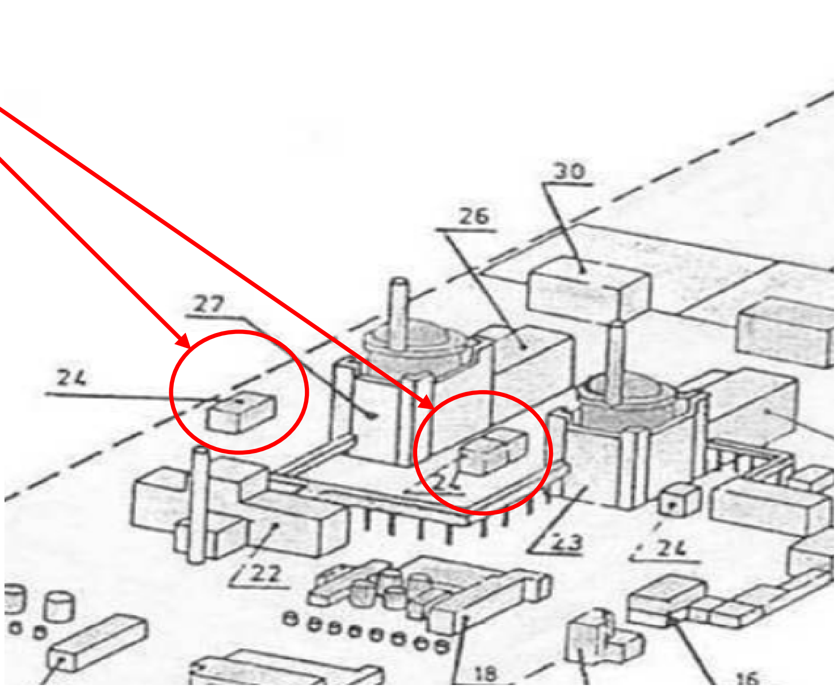
Data for Balakovo NPP (Russian Federation)

Risk Considerations

- Possible scenario – NPP in shutdown mode
- Decay heat removal from fuel in reactor pressure vessel as well as from fuel in spent fuel pool necessary
- Electricity needed – residual heat removal system consists of active components
- Ultimate heat sink necessary – cooling circuits transfer heat, but heat sink necessary – Dnipro river, cooling pond, water from fire brigade trucks, water from wells, air coolers, ...

VVER-1000/320 – Station Blackout

- Loss of all AC Power (Station Blackout SBO)
  - Line to the power grid
  - 3 x 100% Emergency Diesel Generator
  - DGs situated in one building
  - Houseload operation mode limited reliablity



- In case of SBO
  - Original design VVER1000 battery requirement (for valves) – only 30min, in practice, a view hours
  - Without operator interventions: ~3h to core uncovery
  - With operator interventions: ~10h to core uncovery
  - Core meltdown and reactor pressure vessel RPV failure – another 3-5h

Severe Accident Main Phenomena

- Loss of ultimate heat sink, loss of power
- Boiling off of or loss of coolant –spent fuel pool, reactor cooling system
- Once dry out of reactor core or fuel in spent fuel pool: heat up of core and core melt
- Steam – Zirconium reaction, hydrogen generation
- Severe accident: reactor pressure vessel melt, containment failure either through overpressure or basemat melt through

Introduction VVER1000 / Primary System

Power operated relief valve
(G = 50kg/s)

Steam Generator
(P=6.27 MPa, T=278°C, G=408kg/s)

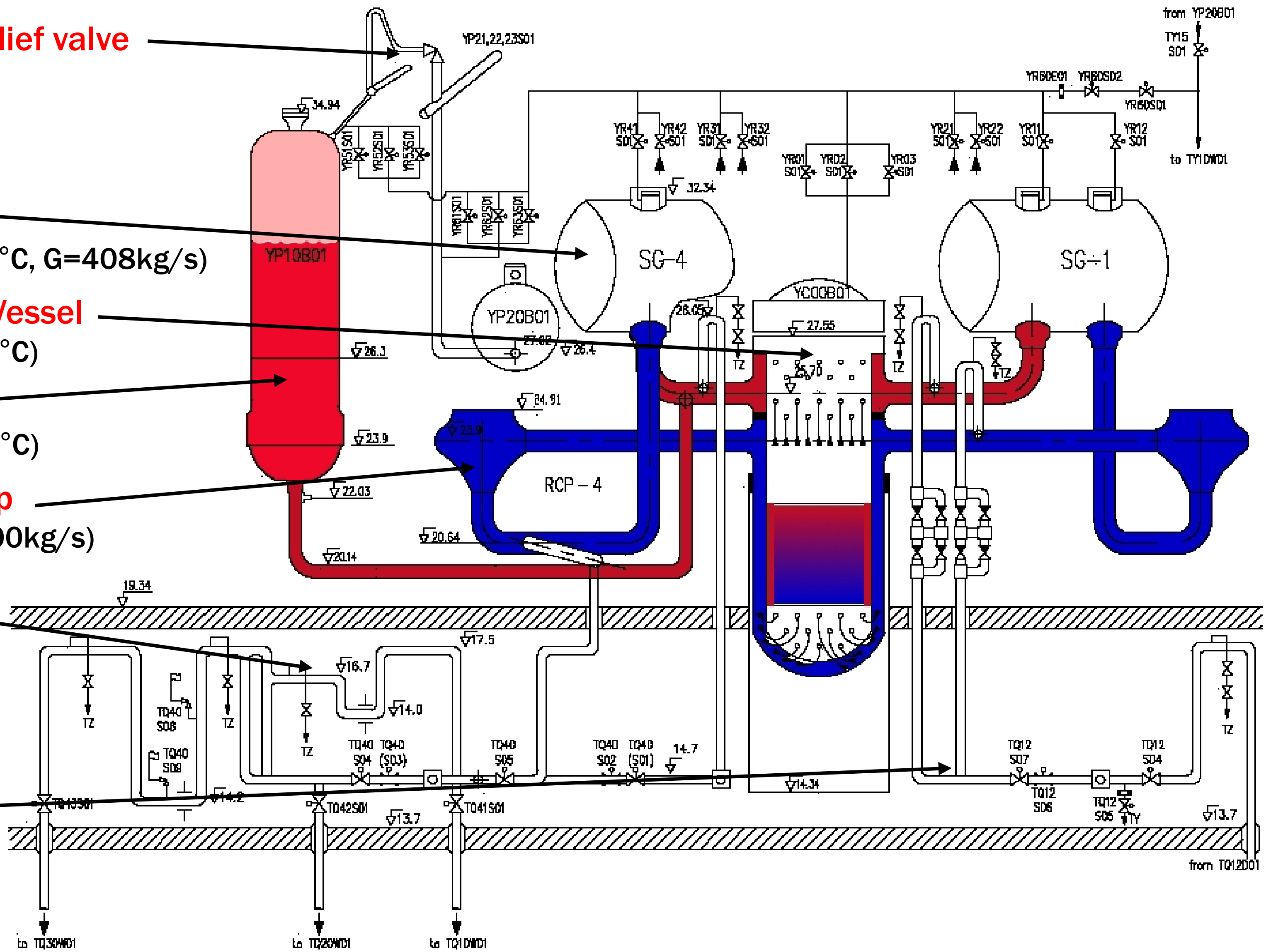
Reactor Pressure Vessel
(Ti=289.7°C, To=320°C)

Pressurizer
(P=15.7 MPa, T=344°C)

Main coolant pump
(G=21200m3/h, 4400kg/s)

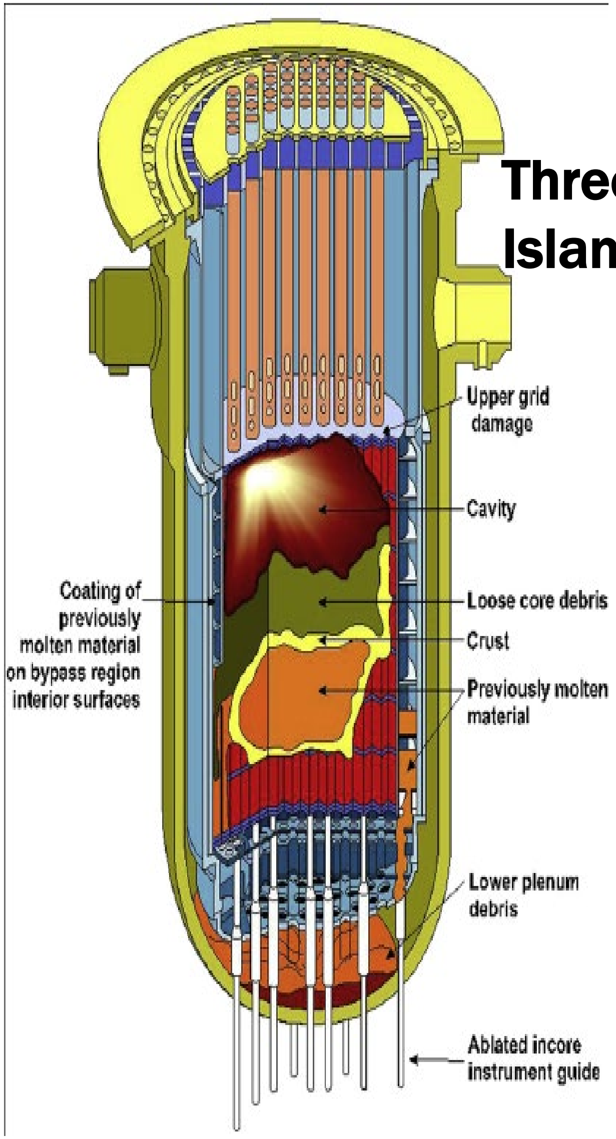
Chemical and volume control system

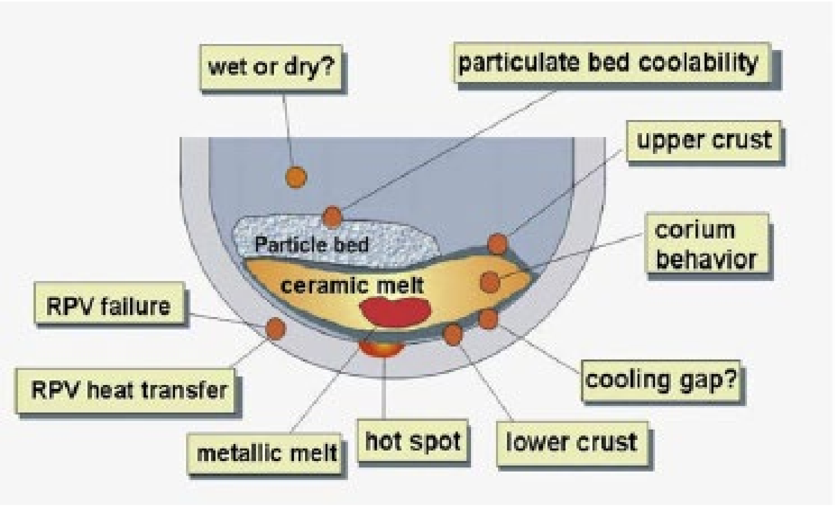
Low pressure injection system (one train)



Severe Accident

Three Mile Island RPV

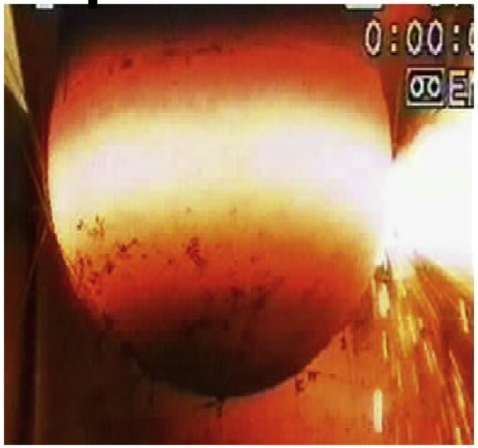




"Severe Accident"

Next Barrier: "Failure Reactor Pressure Vessel"

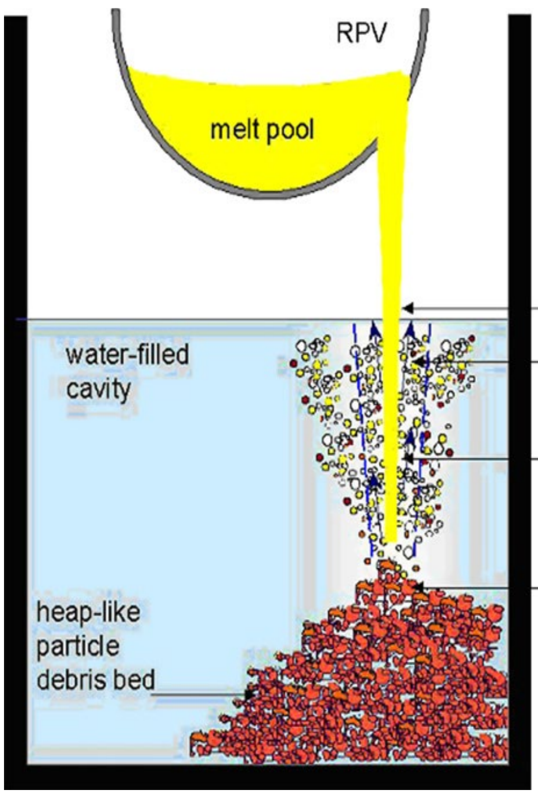
FOREVER Experiment

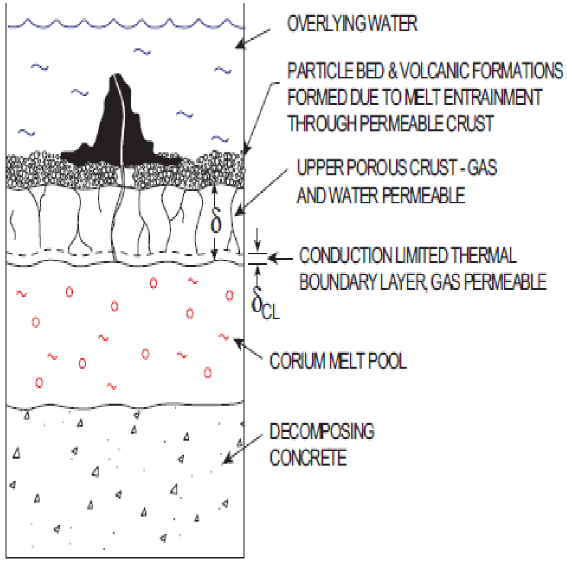


Molten core concrete interaction / late containment failure

In case RPV fails at less than 2-3 MPa:

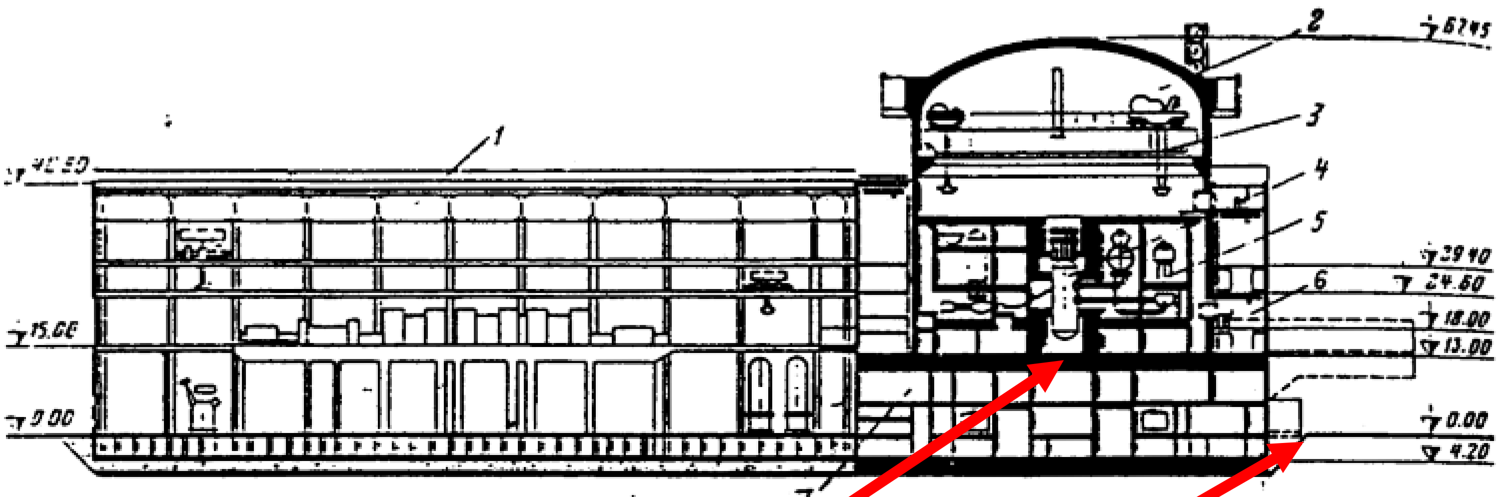
Attack on reactor cavity bottom concrete





VVER-1000/320 – Risks in Conflict

- Basemat melt-through issue



Containment Basemat

Level 0m

Flexrisk Project

- Project at BOKU University to evaluate risk from large radioactive releases from nuclear power plants

- http://flexrisk.boku.ac.at

- Results shown here for Zaporizhia NPP :
  - Weather related probability for Cesium-137 contamination
  - Assumption – accident at one unit leads to release of 20% of the reactor core inventory of Cesium

- Method: ~3000 dispersion calculation in the years 1999-2009, results superimposed. Dates selected cover all seasons and day- and night times

Probability of deposition 1480 kBq/m2

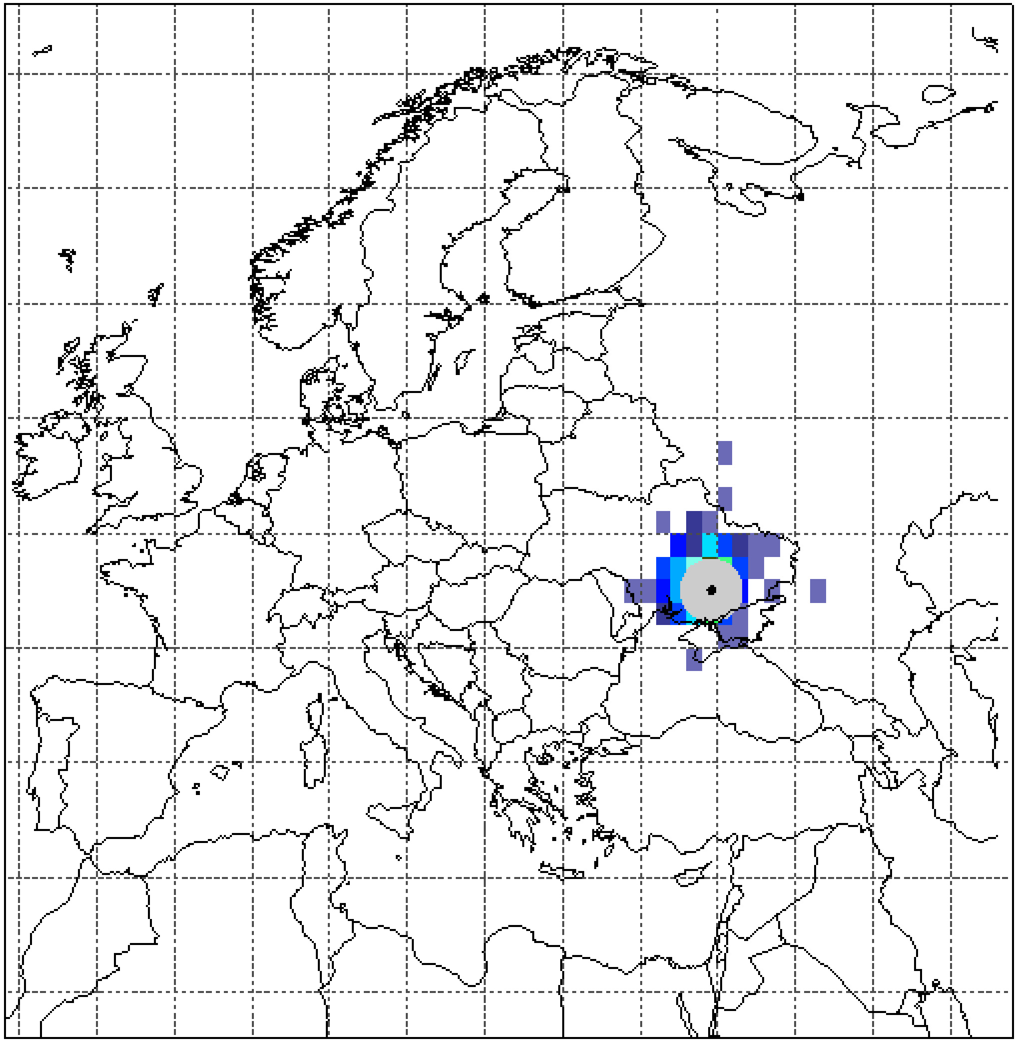
- First shown result – probability of deposition of more than 1480 kBq Cs-137/m2 (40 Ci/km2)

- Value taken from Chernobyl accident – reference value to establish exclusion zone around NPP

- Such contamination would require measures such as relocation or large scale decontamination efforts

Zaporoshje-1

[Weather-related] Probability of deposition >1480.00 kBq Cs-137/m2
Maximum in AT 0.00 %



Probability of deposition 185 kBq/m2

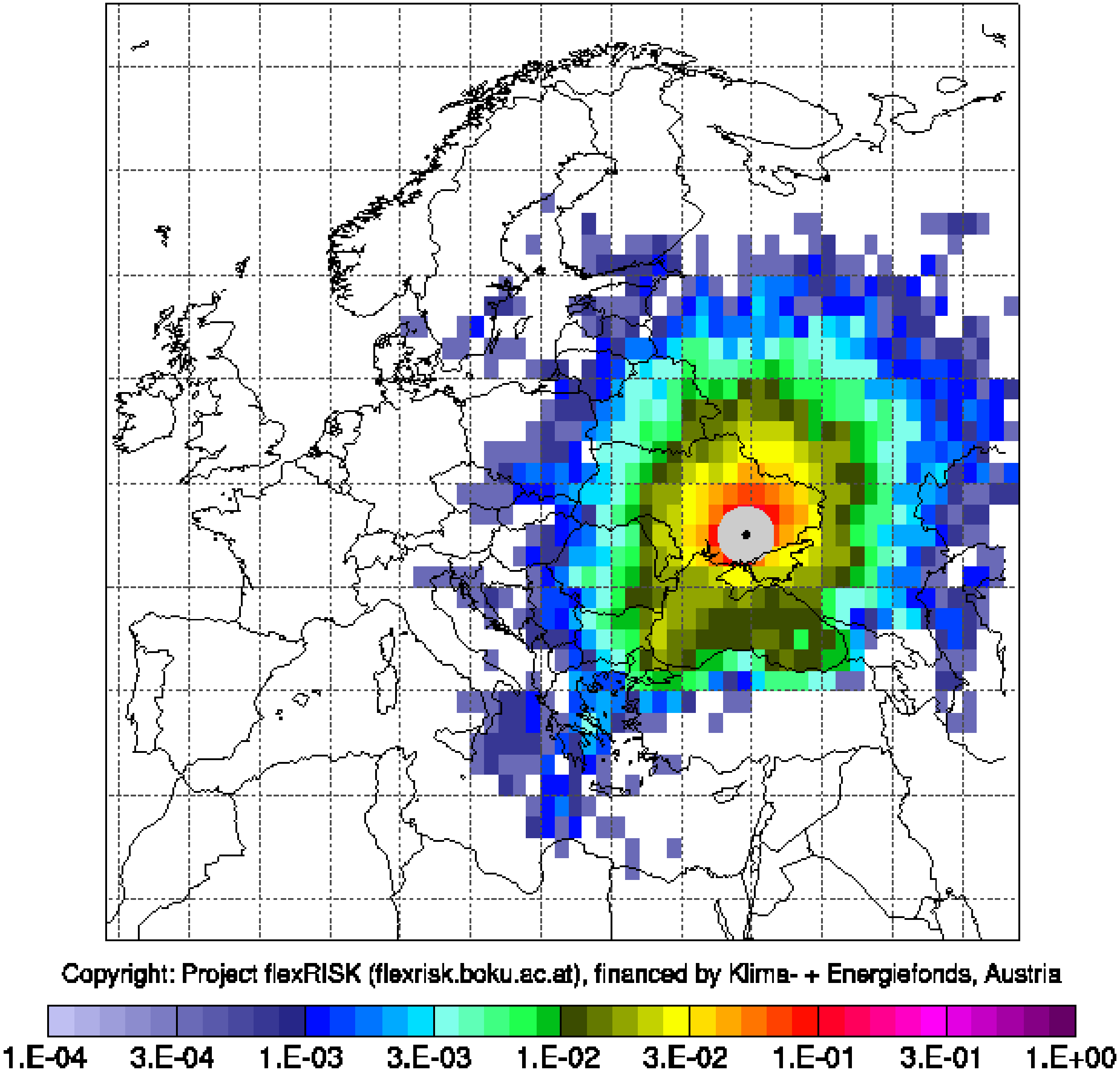
- Second shown result – probability of deposition of more than 185 kBq Cs-137/m2

- Dose stemming from such contamination would not require drastic measures, but would have consequences
  - Agricultural use of land
  - Accumulation in mushrooms
  - Accumulation in venison

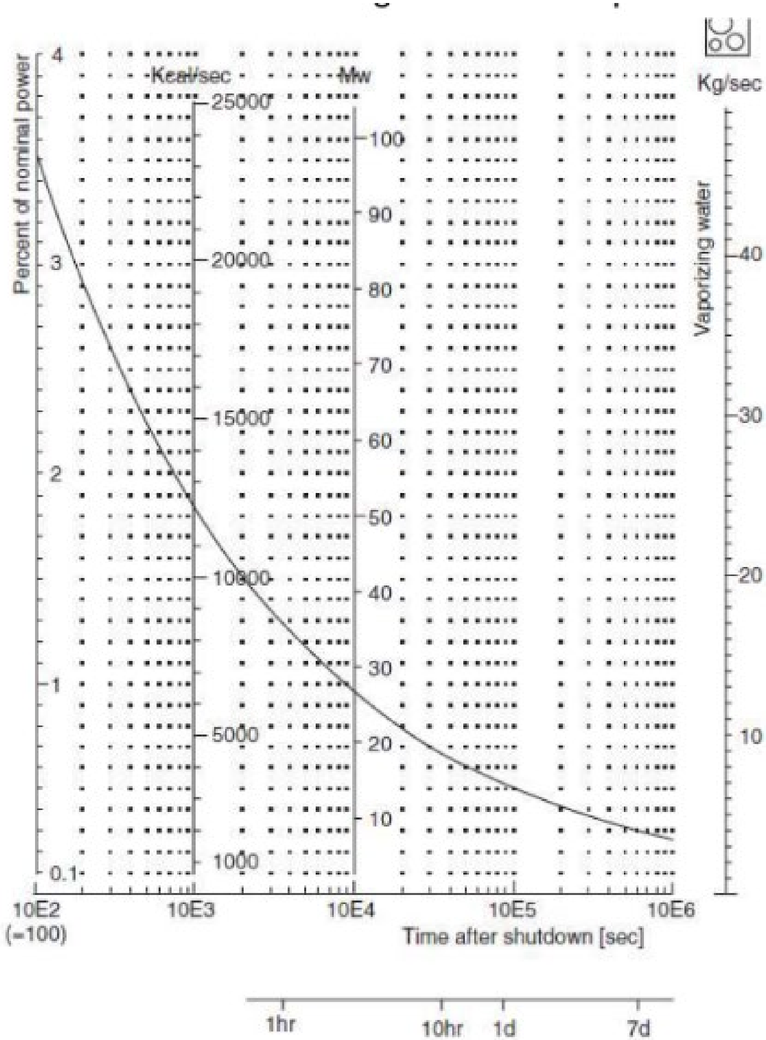
Zaporoshje-1

[Weather-related] Probability of deposition > 185.00 kBq Cs-137/m2

Maximum in AT 0.04 %



Importance of shutdown – decay heat



Time	Decay heat (3000 MW)	%	Water needed kg/s (evaporation)
100 s	105	3,5	46.6
1 hr	30	1,0	13
1 wk	9	0,3	4
1 month	3	0,1	1.33
1 year	1.5	0,05	0.66

Conclusions

- Weather related probability shown for contamination with Cs-137 following a release of 20% of core inventory of one unit
- Contamination of more than 1480 kBq / m2 likely to be restricted to Ukraine
- Probability for contamination of more than 185 kBq / m2 not negligible for a large part of Europe
- Assumed source term – one unit, 20% core inventory – not considered: multi-unit releases, releases from spent fuel pool
- Risk Mitigation: Shut down reactors – time in shut down state prolongs the "Grace Period“. Six month shutdown extends time to react to 1-2 weeks

Thank you

Any questions?