Feedback on the use of risk metrics for L2 PSAs

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Severe Accidents Department

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PSAM 14
September 2018

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1. INTRODUCTION

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- IRSN develops its own L2 PSAs for the French NPPs with significant efforts to have a realistic modelling of the severe accident progression
  - Separated model approach
  - Set of software tools all designed by IRSN engineers and researchers (PSAM 13)

1. INTRODUCTION

- IRSN develops its own L2 PSAs for the French NPPs with significant efforts to have a realistic modelling of the severe accident progression
  - Separated model approach
  - Set of software tools all designed by IRSN engineers and researchers (PSAM 13)

- Choosing an appropriate set of risk metrics → Understanding and ranking the severe accident consequences → Identifying the main contributors to the overall risk → Finding out safety improvements

2. SEVERE ACCIDENT CONSEQUENCES

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Objectives assigned

- Characterization of severe accident consequences is a key step in the evaluation of risks

- Objectives assigned to the assessment of severe accident consequences
  - To take into account the chronology and the uncertainties related to the assessment of radioactive releases
  - To provide realistic orders of magnitude with very short calculation times

- Development of two software

2. SEVERE ACCIDENT CONSEQUENCES

MER software: radioactive releases

- Amplitude and kinetics of radioactive releases
- Models introduced in MER are mainly simplified models from the ASTEC code, also developed by IRSN
- MER is validated by cross-checking with ASTEC
- Three fission products groups
  - Aerosol
  - Halogen (iodine)
  - Noble gas

2. SEVERE ACCIDENT CONSEQUENCES

MERCoR software: radiological consequences

- Dose and ground deposition
  - Over the first 90 kilometers from the NPP and the first 30 days after the initiating event
  - One given standard meteorological condition
  - 1-year-old-child exposed to the radioactive plume in the wind axis
- Exposure pathways
  - External exposure from the plume and from ground deposition
  - Internal exposure from inhalation
  - *Internal exposure from ingestion is planned in the years to come*
- Radionuclides considered cover 99% of the radiological consequences

3. RISK METRICS FOR L2 PSAs

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↗ IRSN multi-criteria approach with a set of risk metrics

- History of L2 PSAs presented results at IRSN
  - Until 2007
    - Frequency of the different containment failure modes
    - Amplitude of radioactive releases in Becquerel

      → Consistent with the definition of a L2 PSA but difficulty to have a good understanding of the issues associated to the severe accident scenarios

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  - From 2007
    - Frequency of the different containment failure modes
    - ~~Amplitude of radioactive releases in Becquerel~~
    - Short- and long-term radiological consequences

      → Today, this multi-criteria approach provides a better understanding of the consequences of a severe accident

3. RISK METRICS FOR L2 PSAs

↗ IRSN multi-criteria approach with a set of risk metrics

Short-term radiological consequences

- Risk metrics: effective dose and thyroid equivalent dose
- Used in the French Public Health Code to define the protection measures in case of radiological emergencies
- Possible to rank L2 PSAs scenarios according to their short-term consequences

→ **Feedback: highly satisfactory**

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Long-term radiological consequences

- Risk metric: <u>contamination of soils with caesium-137</u>
- Used in the Soviet Union to define the extent of contaminated territories after the Chernobyl accident
- Possible to rank L2 PSAs scenarios according to their long-term consequences

→ **Feedback: highly satisfactory**

3. RISK METRICS FOR L2 PSAs

Extension of the current set of risk metrics with a communication tool

- New risk metric: radiological equivalence to iodine-131 for releases to the atmosphere (in Bq), used to define the INES

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➚ Extension of the current set of risk metrics with a communication tool

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- The INES
  - Developed in 1990 by IAEA to allow prompt communication of the significance of a nuclear event
  - 7 levels
  - 20 radionuclides considered (caesium-137, plutonium-239, strontium-90, …)
  - Principle: to apply multiplying factors to the activity released for a given radionuclide to provide an iodine-131 equivalent activity
  - Factors are calculated by considering the effective dose with exposure from inhalation (short-term) and ground deposition over 50 years (long-term)

    → External exposure from the plume not considered

    → Noble gases are neglected

3. RISK METRICS FOR L2 PSAs

➚ Extension of the current set of risk metrics with a communication tool: the INES

- Feedback on the use of the INES for presenting L2 PSAs results
  - Possible to associate an INES level to each L2 PSA scenario
  - However some limitations of the INES have been highlighted

→ **Feedback: not fully satisfactory**

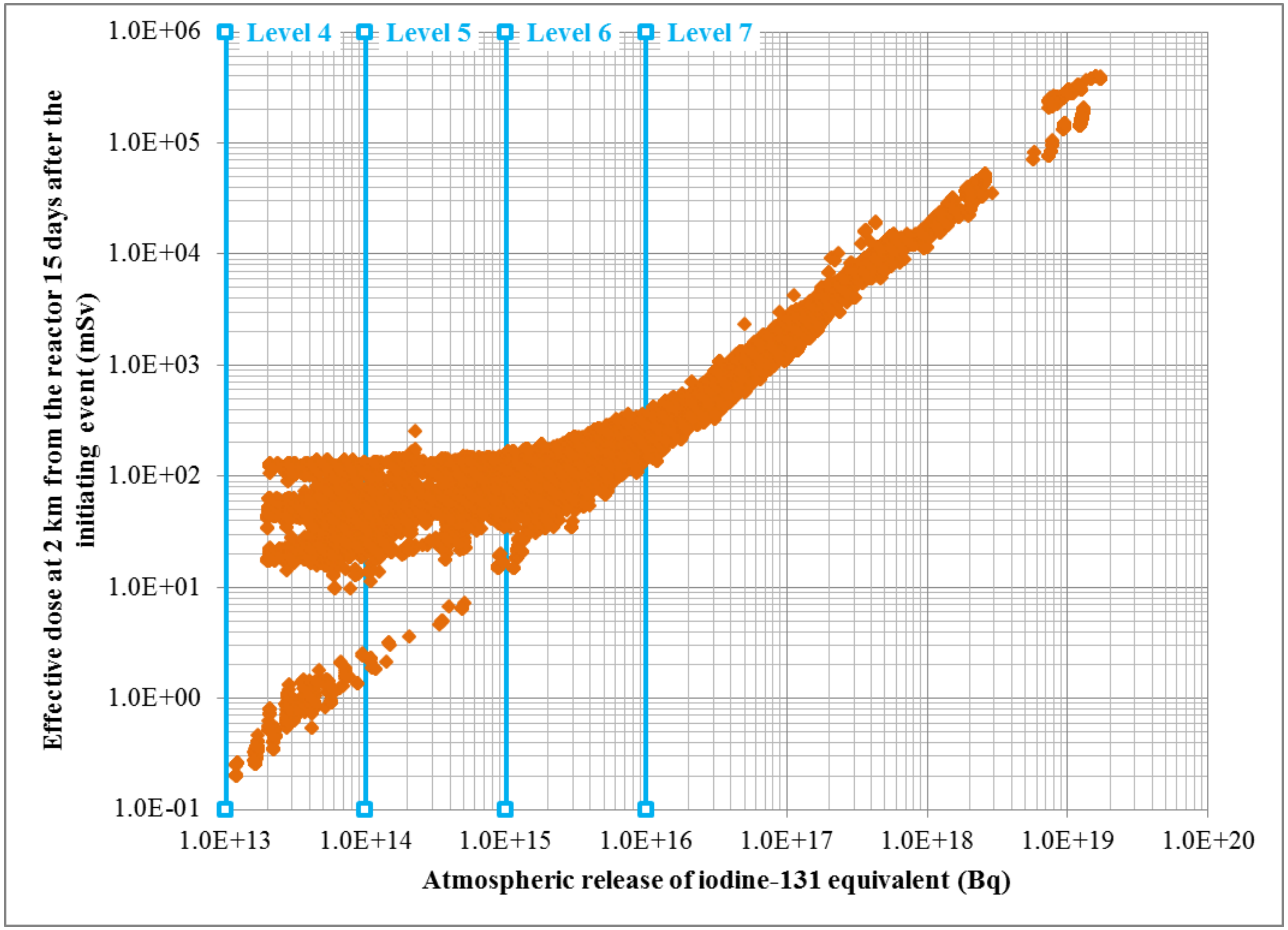
- The following explains what the limitations are,
  by using the results of the last French 900 MWe PWRs internal initiating events L2 PSA study

  → ~ 500,000 severe accident scenarios

  → ~ 50,000 release categories

3. RISK METRICS FOR L2 PSAs

➚ Extension of the current set of risk metrics with a communication tool: the INES



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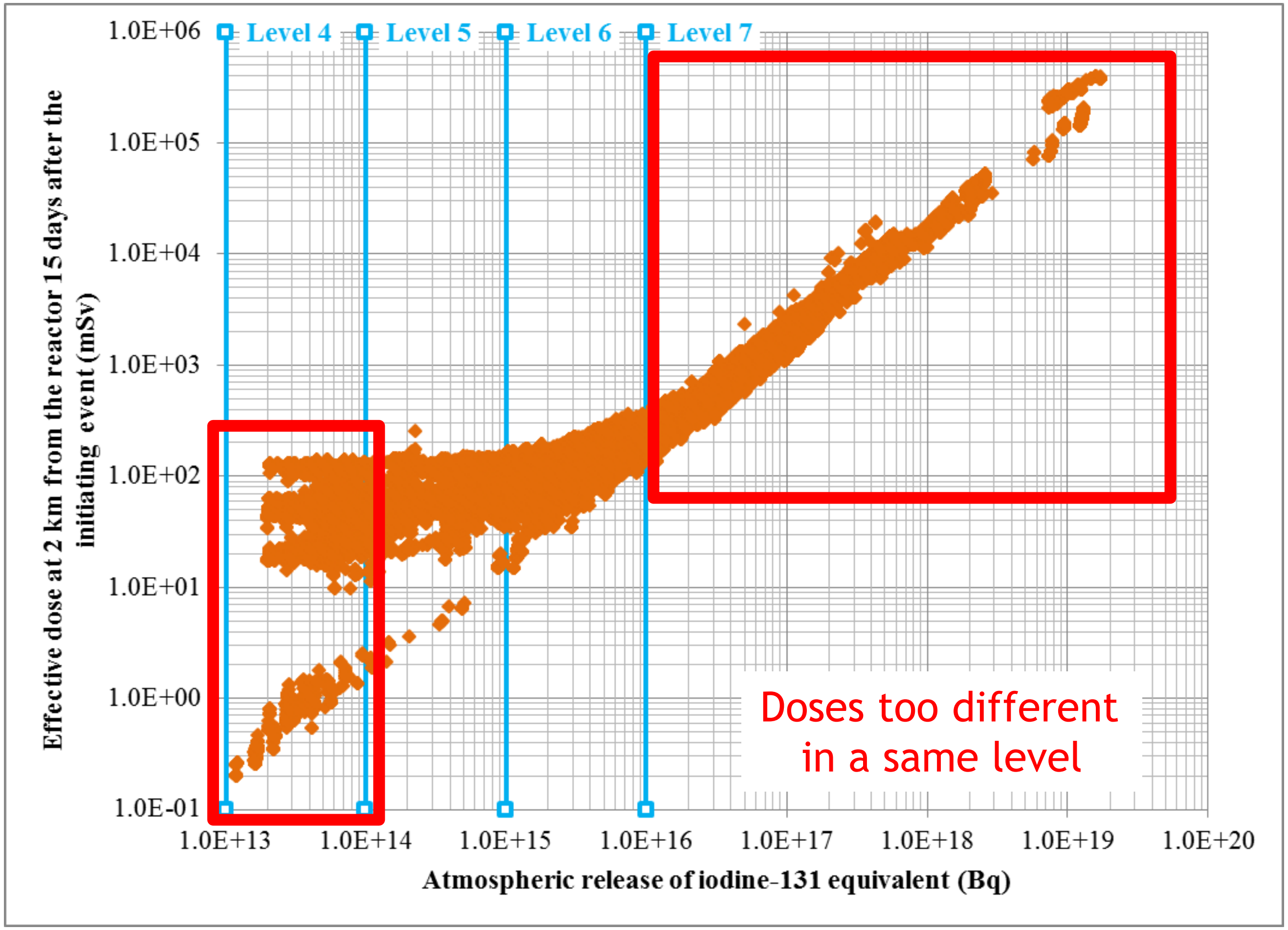

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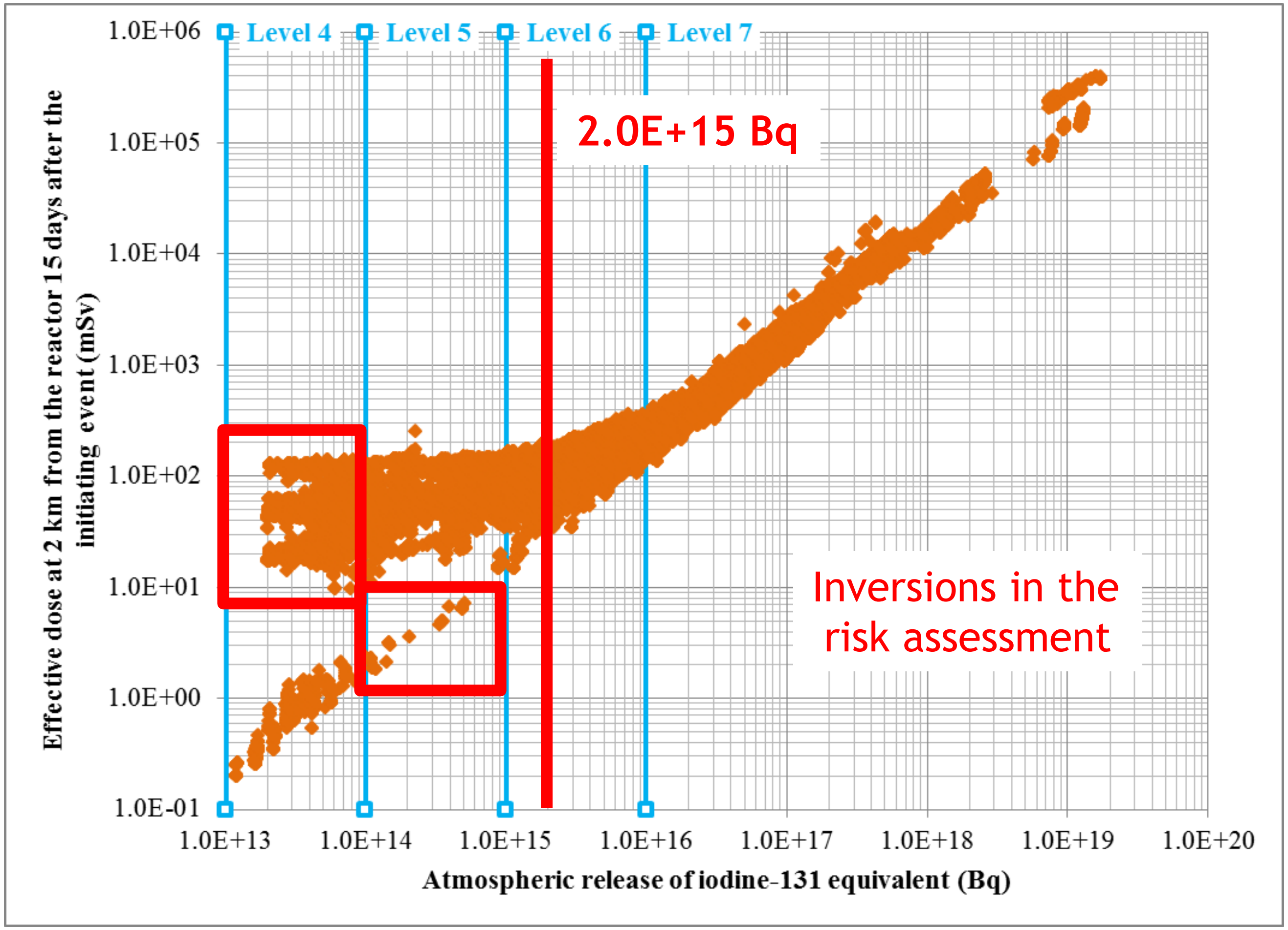

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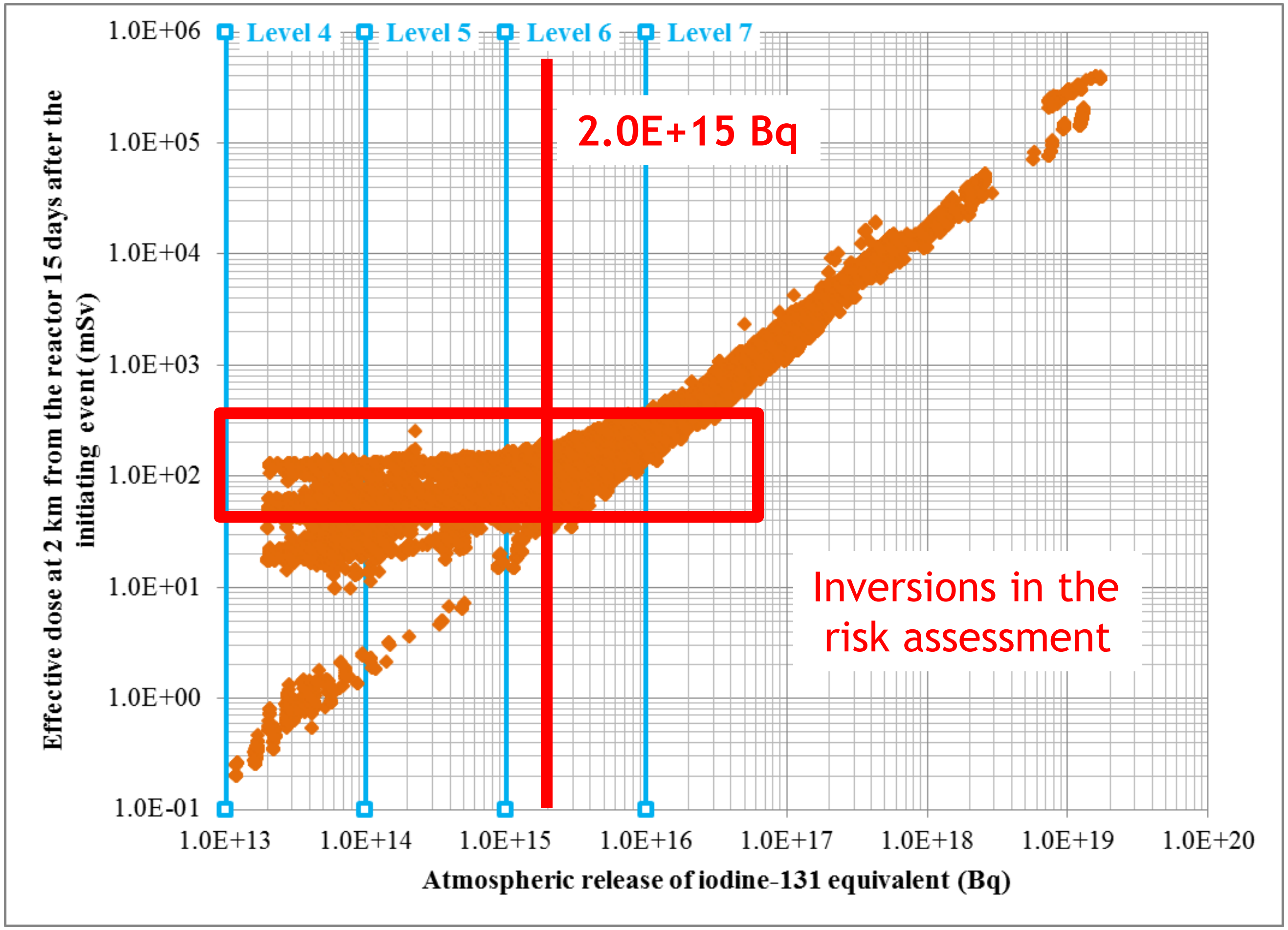

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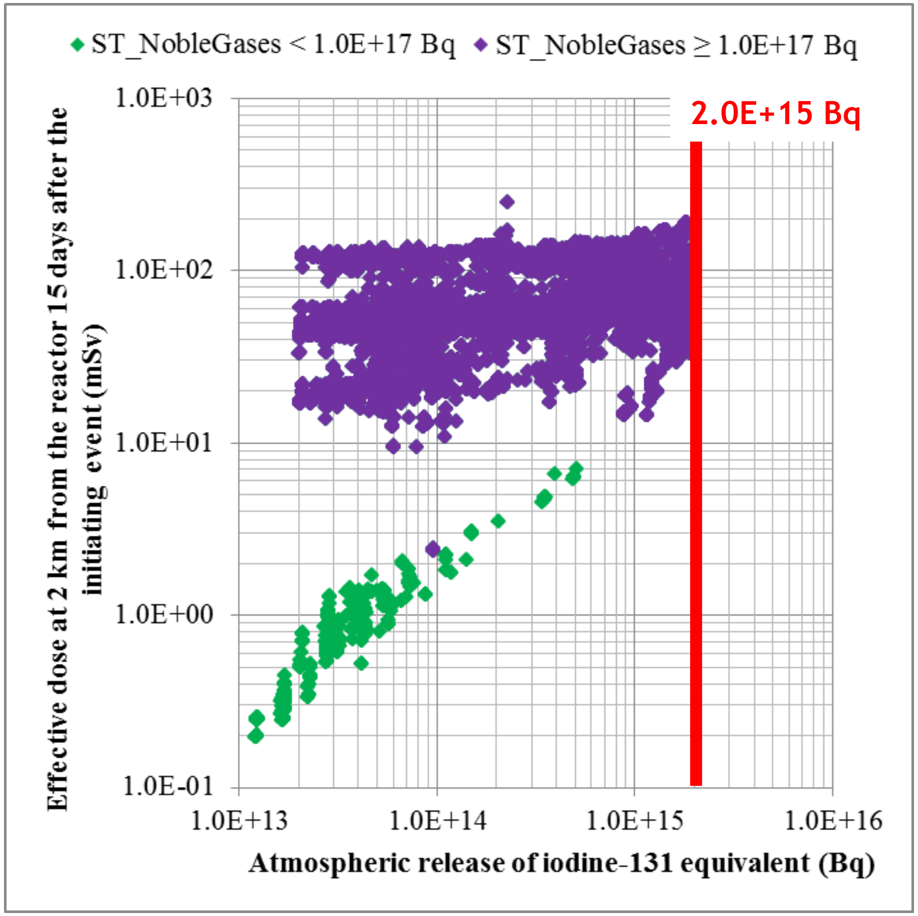

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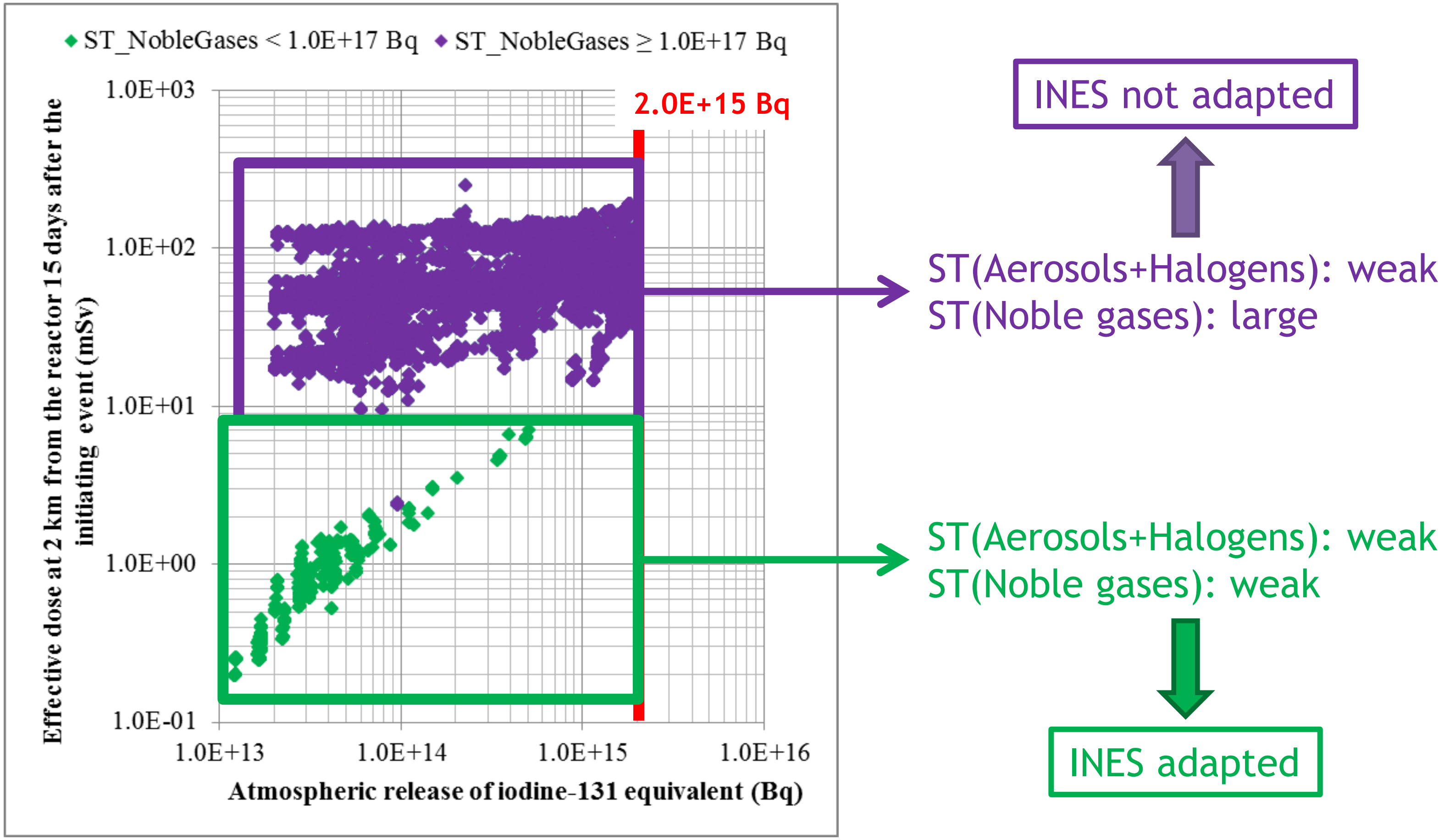

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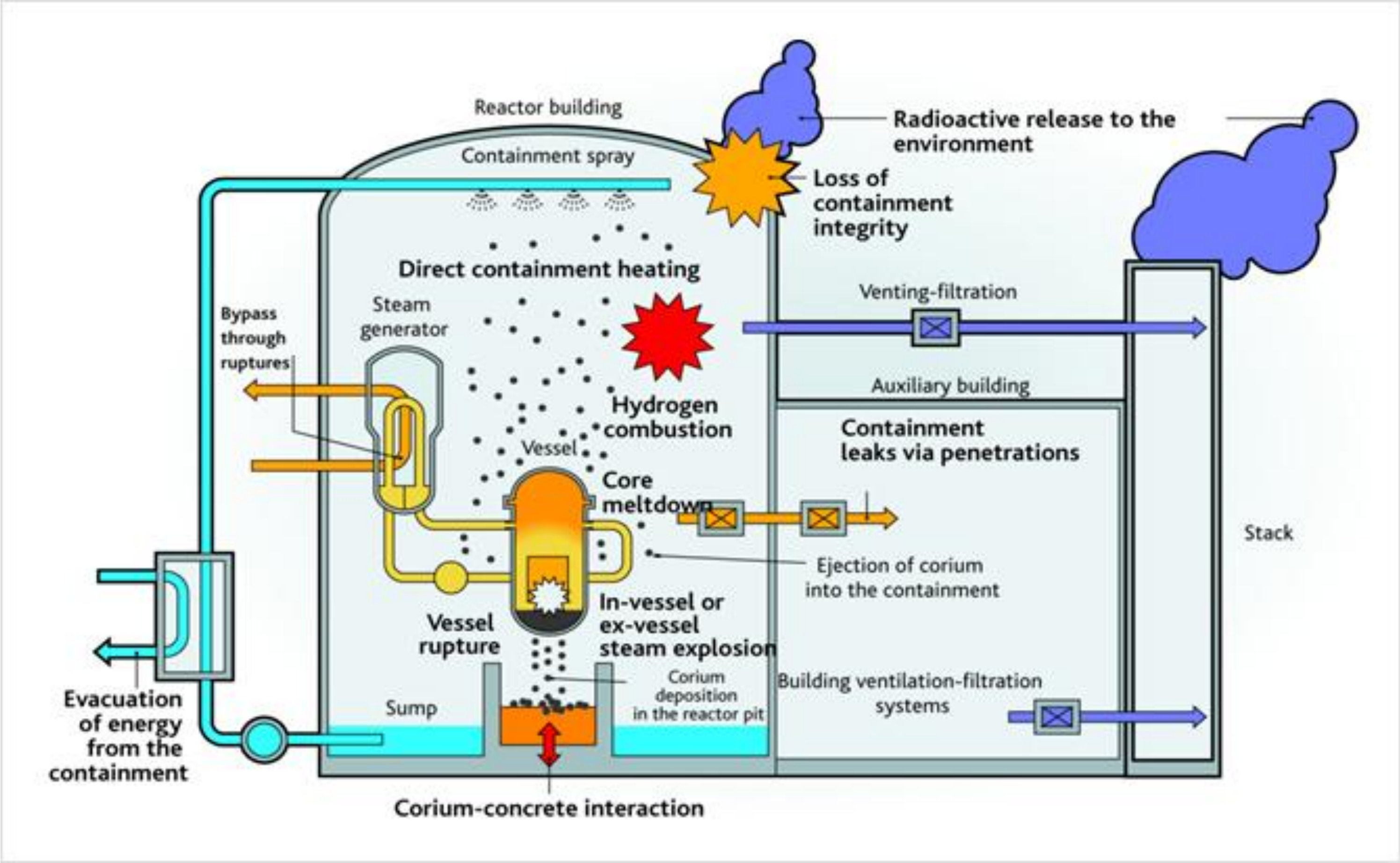
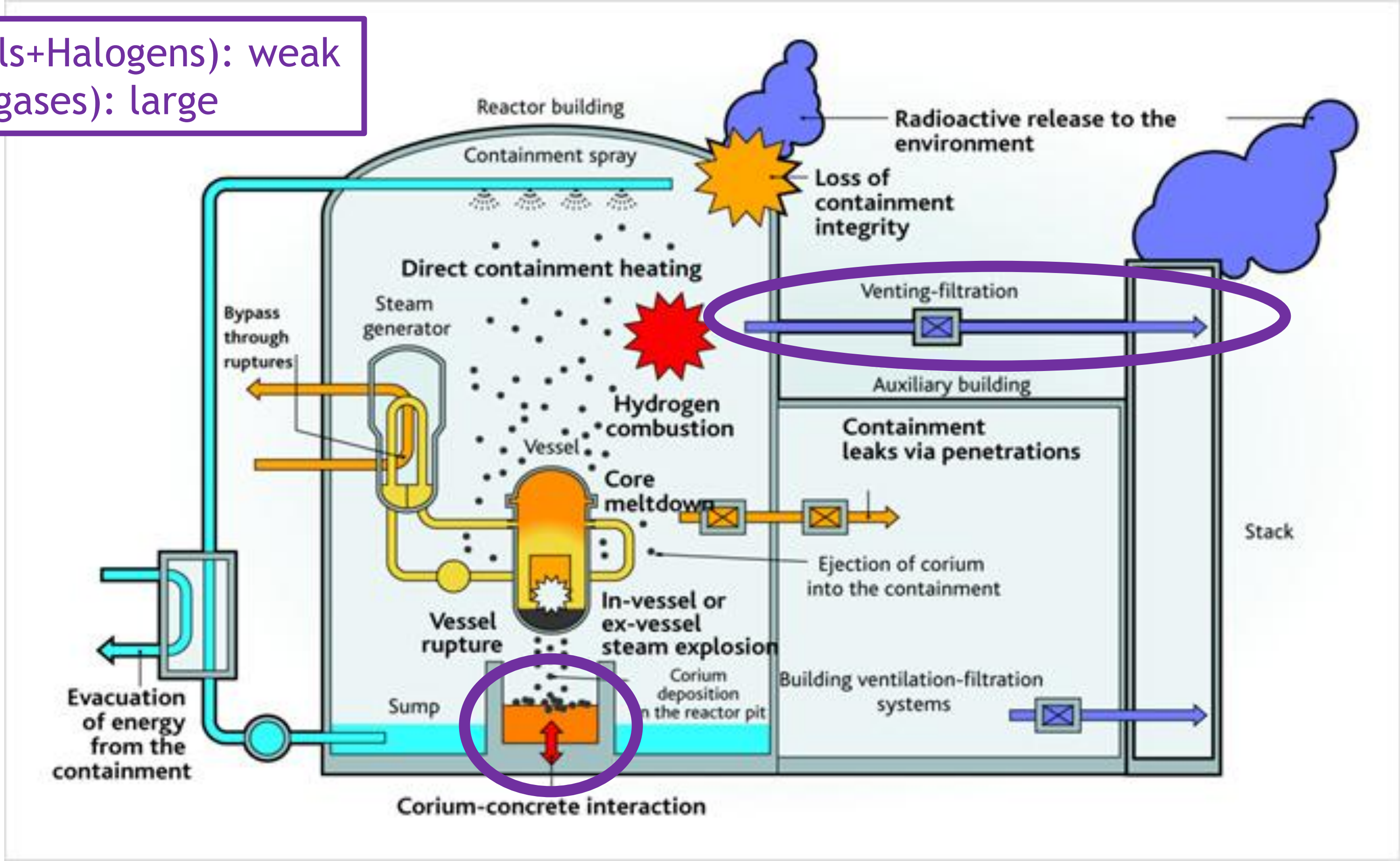
- **Extension of the current set of risk metrics with a communication tool: the INES**



3. RISK METRICS FOR L2 PSAs

➚ Extension of the current set of risk metrics with a communication tool: the INES

ST(Aerosols+Halogens): weak
ST(Noble gases): large



4. CONCLUSION

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- IRSN multi-criteria approach with a set of risk metrics
  - Short-term: effective dose and thyroid equivalent dose
  - Long-term: contamination of soils with caesium-137
  - Quite useful and satisfactory for ranking L2 PSAs severe accident scenarios

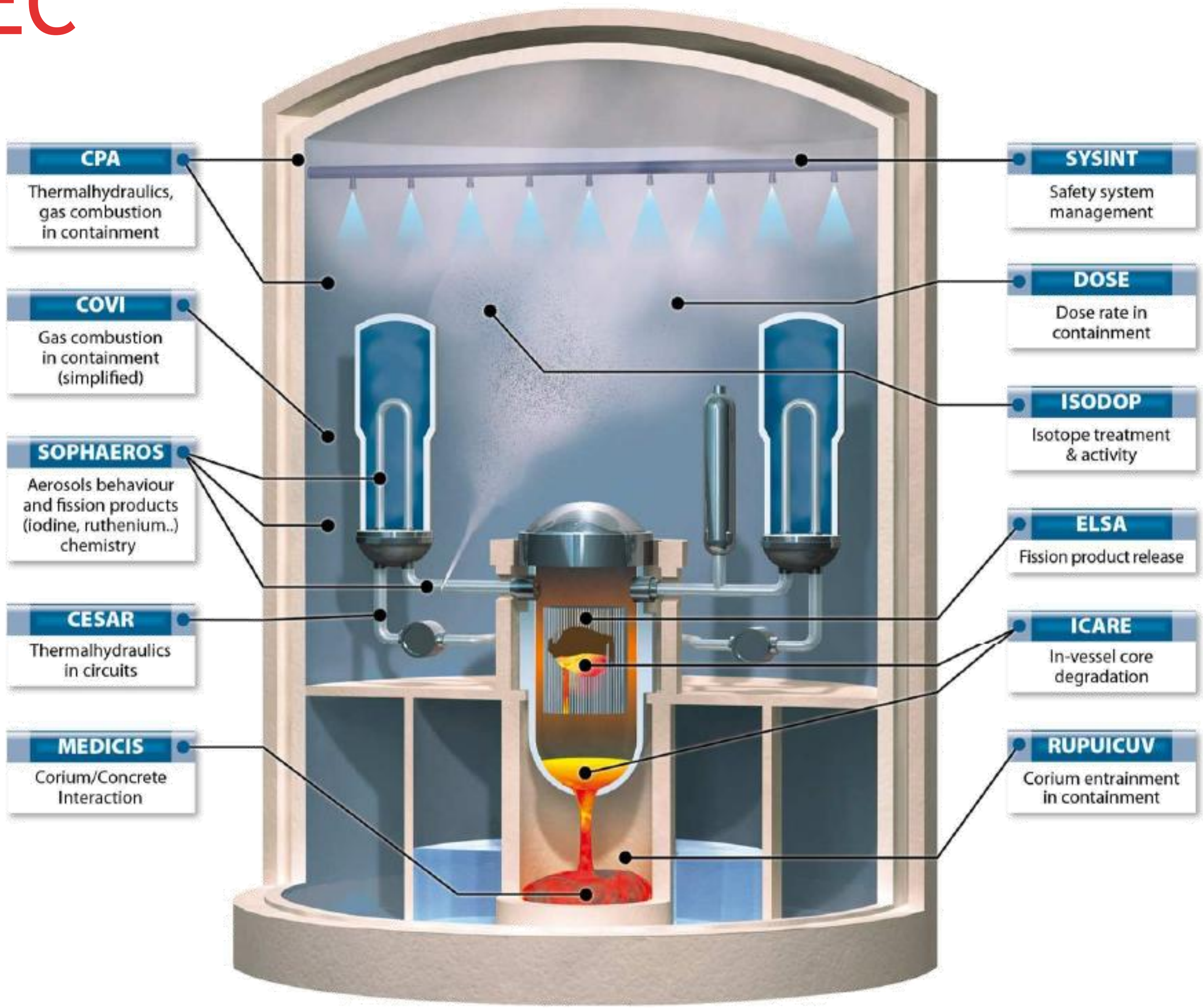
- Use of the INES as a communication tool for presenting L2 PSAs results
  - Interesting feedback as each L2 PSA scenario can be associated to an INES level
  - However some limitations of the INES have been found
    - Neglect of the noble gases contribution
    - Level 7 groups scenarios whose radiological consequences are too different
  - The INES is not fully adapted to be used as a risk metric for L2 PSAs
    but constitutes an interesting starting point to define the requirements associated to the development in the future of one risk metric

Thank you

for your attention

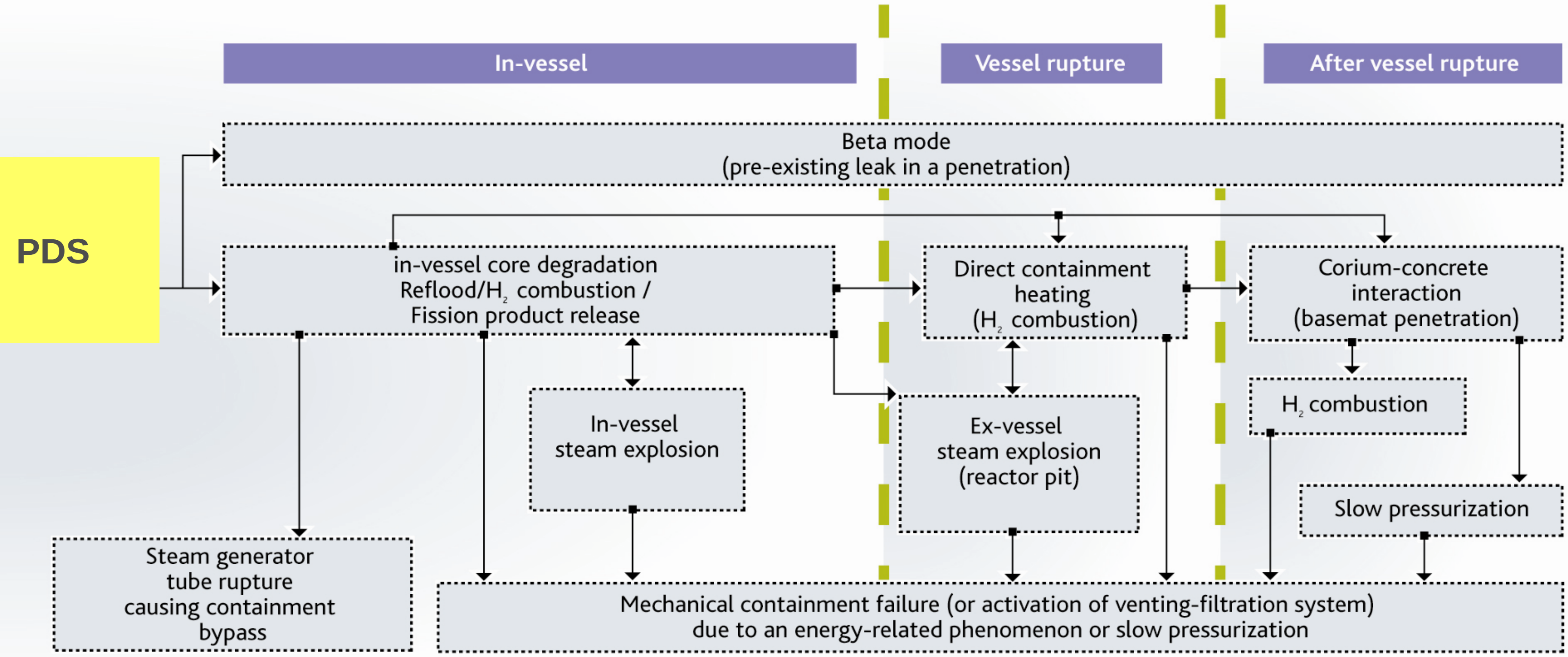
ANNEXES

ASTEC



CPA
Thermalhydraulics, gas combustion in containment
COVI
Gas combustion in containment (simplified)
SOPHAEROS
Aerosols behaviour and fission products (iodine, ruthenium..) chemistry
CESAR
Thermalhydraulics in circuits
MEDICIS
Corium/Concrete Interaction
SYSINT
Safety system management
DOSE
Dose rate in containment
ISODOP
Isotope treatment & activity
ELSA
Fission product release
ICARE
In-vessel core degradation
RUPUICUV
Corium entrainment in containment

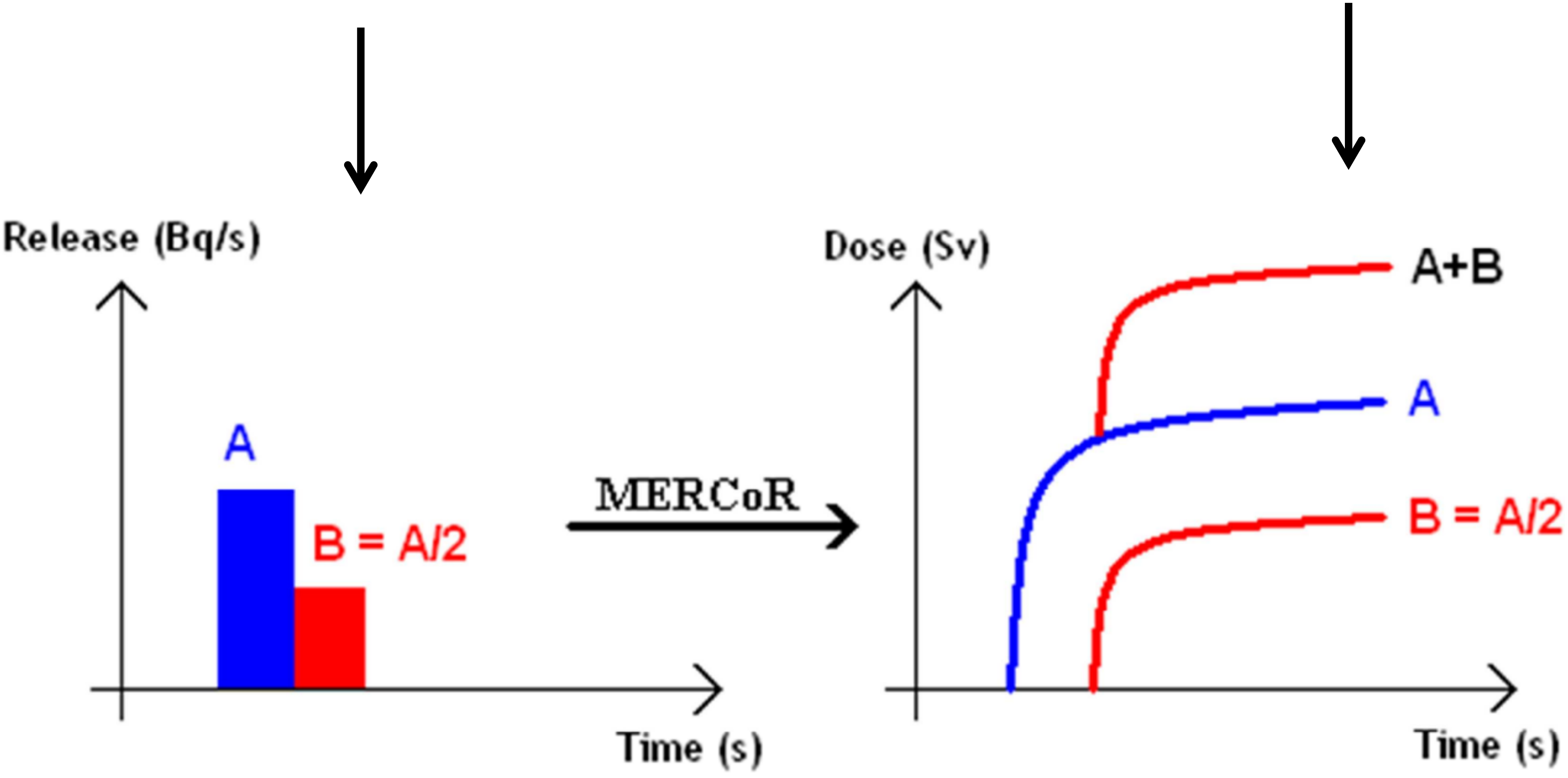
PHYSICAL PHENOMENA INCLUDED IN THE APET



DOSE CALCULATION WITH MERCoR (1/2)

The release calculated by MER is decomposed into a sum of elementary releases

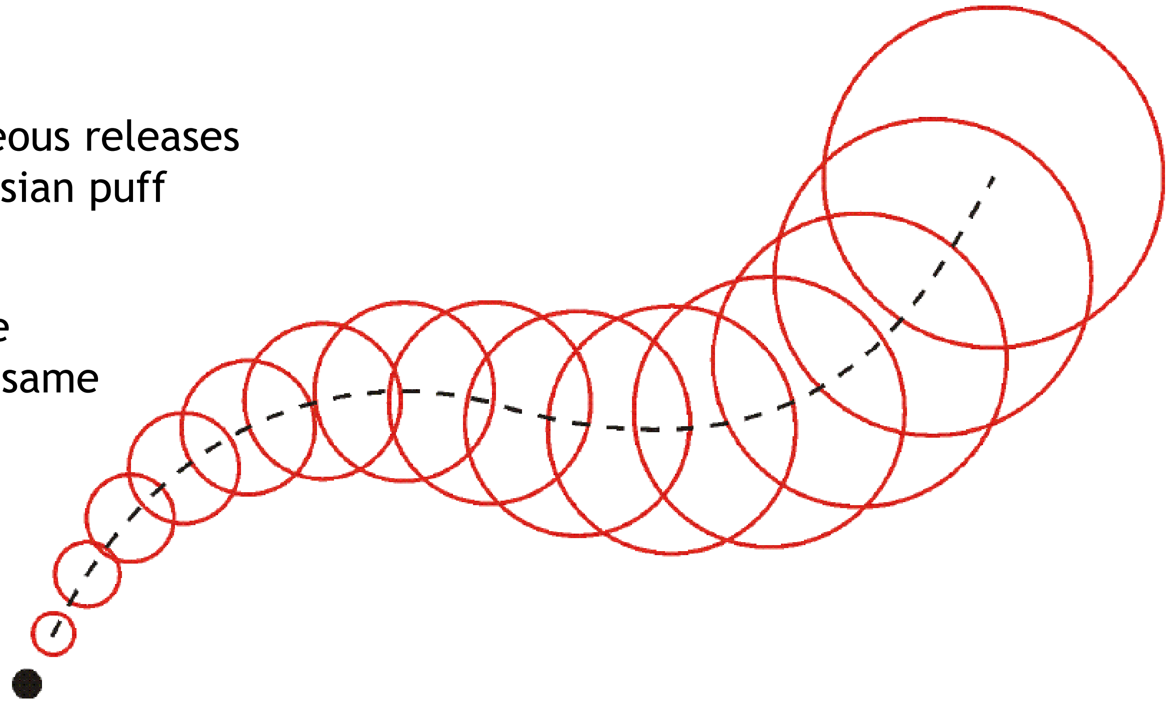
Transfer function



DOSE CALCULATION WITH MERCoR (2/2)

Plume = Succession of instantaneous releases
1 instantaneous release = 1 Gaussian puff

In MERCoR, the axis of the plume
and the axis of the wind are the same



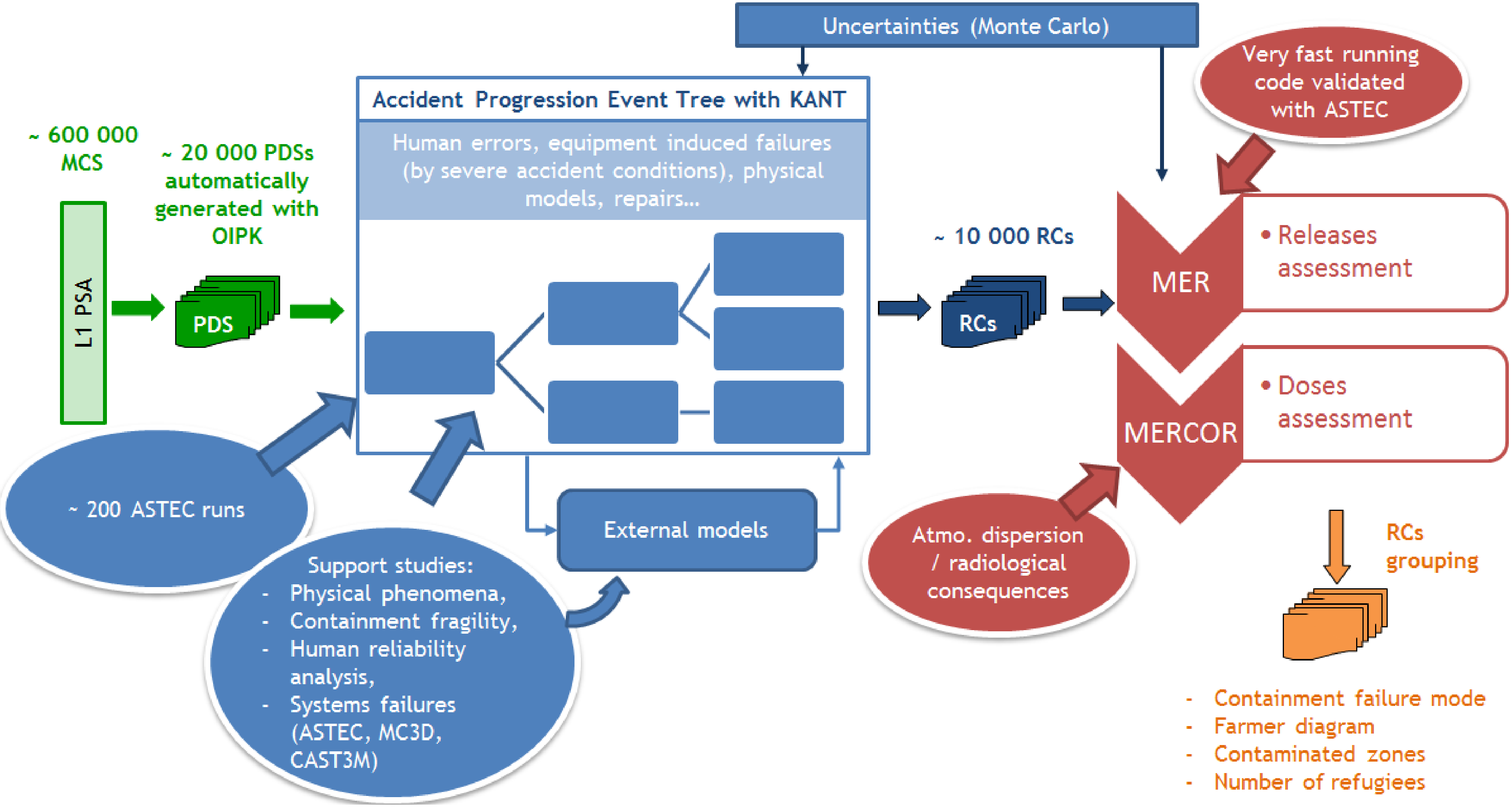

Uncertainties (Monte Carlo)
Accident Progression Event Tree with KANT
Human errors, equipment induced failures (by severe accident conditions), physical models, repairs…
~ 600 000 MCS
~ 20 000 PDSs automatically generated with OIPK
L1 PSA
PDS
~ 10 000 RCs
RCs
Very fast running code validated with ASTEC
MER
• Releases assessment
MERCOR
• Doses assessment
~ 200 ASTEC runs
External models
Support studies:
- Physical phenomena,
- Containment fragility,
- Human reliability analysis,
- Systems failures (ASTEC, MC3D, CAST3M)
Atmo. dispersion / radiological consequences
RCs grouping
- Containment failure mode
- Farmer diagram
- Contaminated zones
- Number of refugiees

Table 1: French intervention trigger levels in case of radiological emergencies [8]

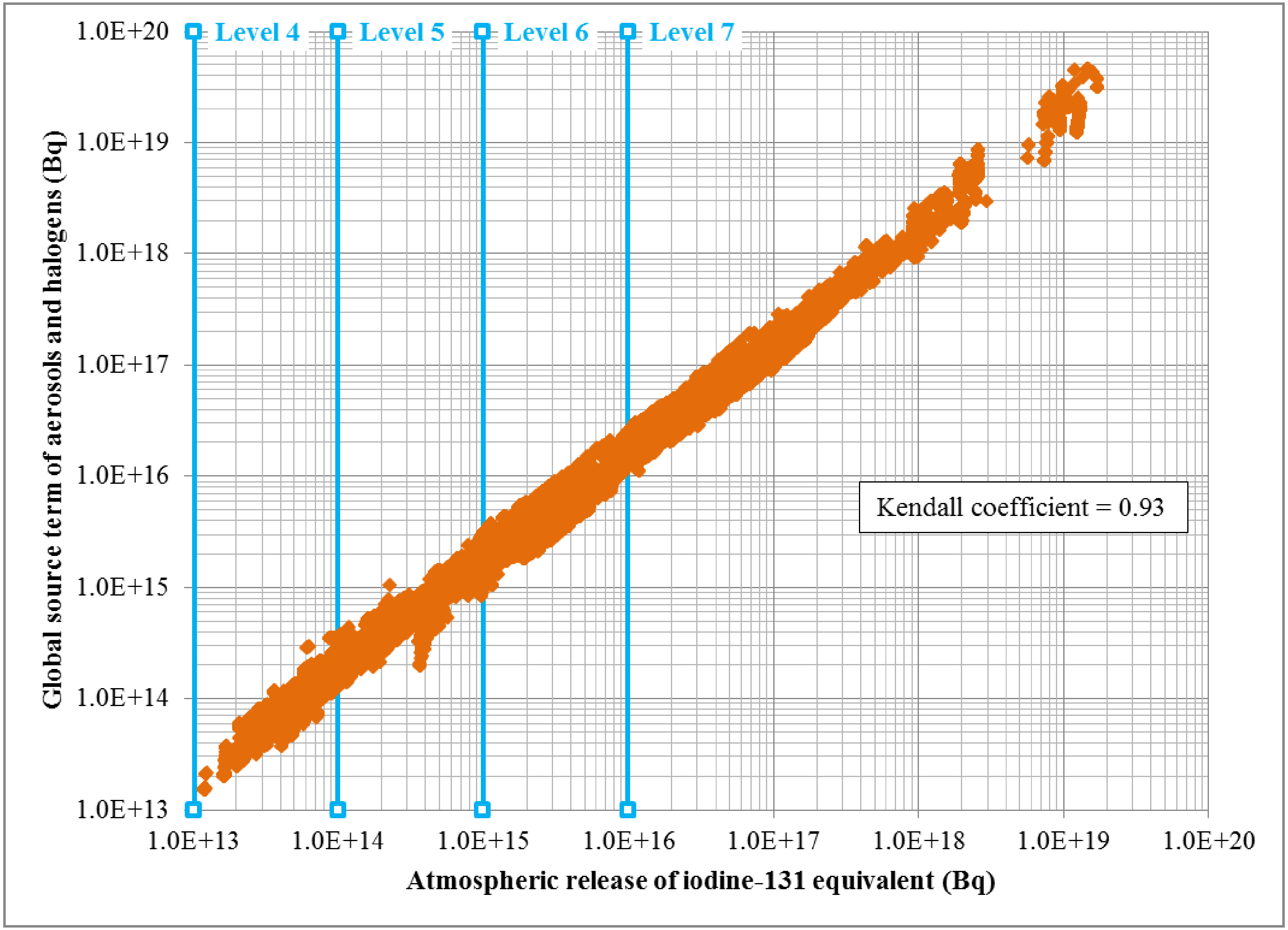
Protection measure	Indicator	Trigger level (mSv)
Sheltering	Effective dose (all pathways of exposure except ingestion)	10
Evacuation		50
Administration of a stable iodine tablet	Thyroid equivalent dose (all pathways of exposure except ingestion)	50

Table 2: Zoning of territories affected by radioactive contamination resulting from the catastrophe at the Chernobyl NPP [9]

Caesium-137 ground deposition (kBq/m^2)	Zone designation in Russian Federation	Zone designation in Belarus	Zone designation in Ukraine	Zone designation in this paper
37–185	Favourable social and economic status	Periodic control	Reinforced radiological control	Radiological control
185–555	Right of relocation	Right to be resettled	Guaranteed voluntary resettlement	Voluntary resettlement
555–1,480	Relocation	Subsequent relocation	Obligatory resettlement	Subsequent resettlement
> 1,480	Obligatory relocation	Immediate resettlement	Obligatory resettlement	Primary resettlement

Table 3: French indicators and guidance values for defining post-accident zoning [12] [2]

Zone	Indicator	Guidance value
Heightened territorial surveillance zone (ZST)	Maximum permitted levels of contamination of foodstuffs	According to foodstuffs
Public protection zone (ZPP)	Effective dose (all pathways of exposure)	> 10 mSv during the first month following the end of release
	Thyroid equivalent dose (all pathways of exposure)	> 50 mSv during the first month following the end of release
Relocation perimeter (PE)	Effective dose (all pathways of exposure except ingestion)	> 10 mSv during the first month following the end of release


Level 4
Level 5
Level 6
Level 7
Global source term of aerosols and halogens (Bq)
1.0E+20
1.0E+19
1.0E+18
1.0E+17
1.0E+16
1.0E+15
1.0E+14
1.0E+13
Kendall coefficient = 0.93
1.0E+13
1.0E+14
1.0E+15
1.0E+16
1.0E+17
1.0E+18
1.0E+19
1.0E+20
Atmospheric release of iodine-131 equivalent (Bq)