# ASNR'S APPROACH TO INTRODUCE COUNTERMEASURES EFFECTS AND HEALTH CONSEQUENCES ASSESSMENT OF NPP SEVERE ACCIDENTS IN PSA

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# ABOUT ASNR

- ASNR is the merge (2025) of the French Safety Authority ASN and its technical support organization IRSN

- ASNR develops L2 PSAs for the French PWRs that provide containment failure modes frequencies and release categories frequencies associated to kinetic and amplitude of releases

- Some complements are currently being developed to model the **health consequences** and the **benefits of protective actions (countermeasures)** in order to provide additional information for emergency preparedness. They are described in this presentation.

# PRESENTATION PLAN

# 01

# INTRODUCTION

# HISTORY OF THE DEVELOPMENTS FOR RADIOLOGICAL CONSEQUENCES ASSESSMENT AT ASNR

Late 90s: IPSN (former IRSN) started developing L2 PSAs for French PWRs to support safety reviews for ASN

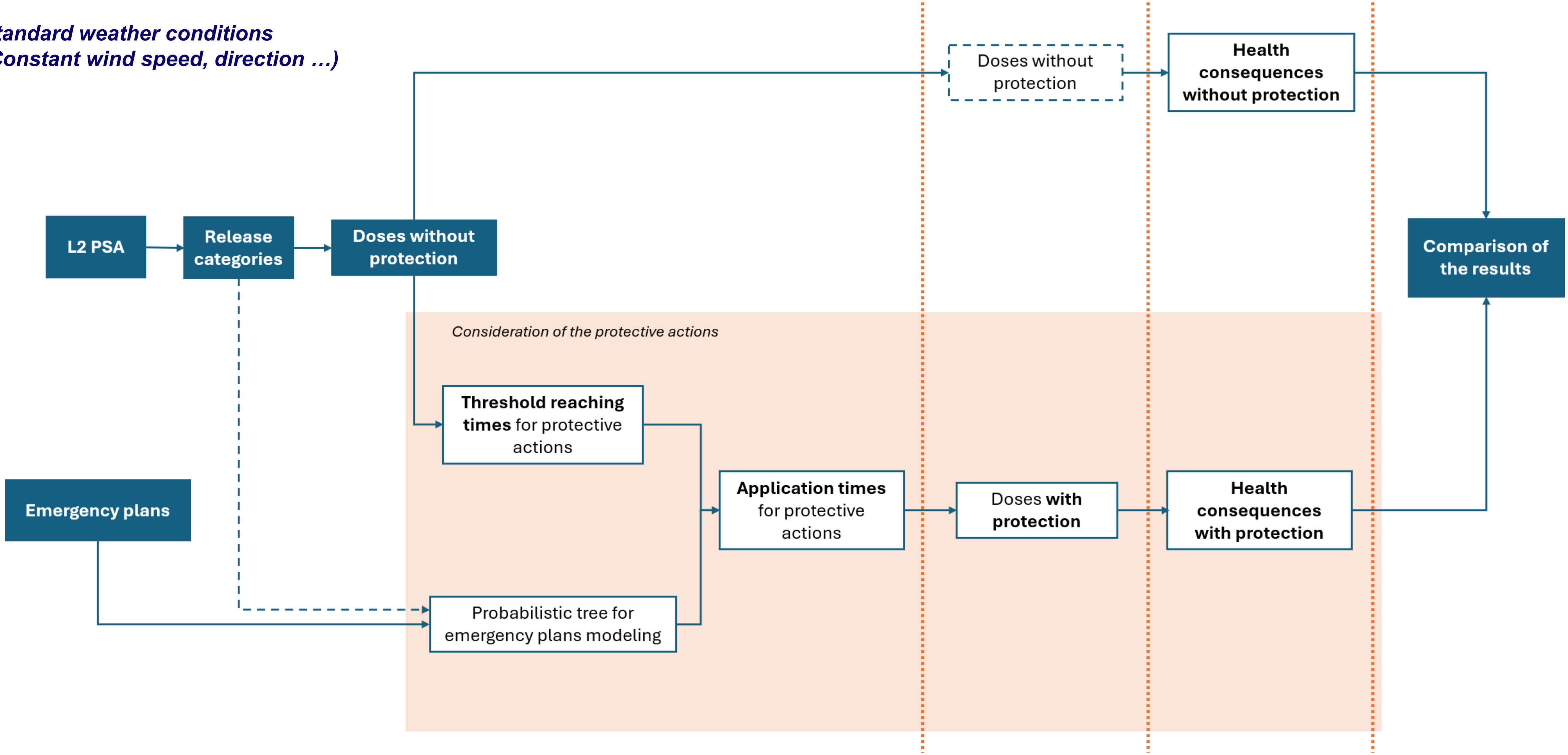
2009: IRSN introduced doses and ground contamination metrics in its L2 PSA for standard weather conditions → Impact of accidents in term of necessary short term countermeasures (L2+ PSA)

**2025 - 2026 : ASNR introduces deterministic and stochastic health consequences of doses and also a modelling of implementation of short-term countermeasures (L3 PSA)**

Post-accident consequences *(not included in this presentation)*

# GLOBAL APPROACH FOR HEALTH CONSEQUENCES ASSESSMENT

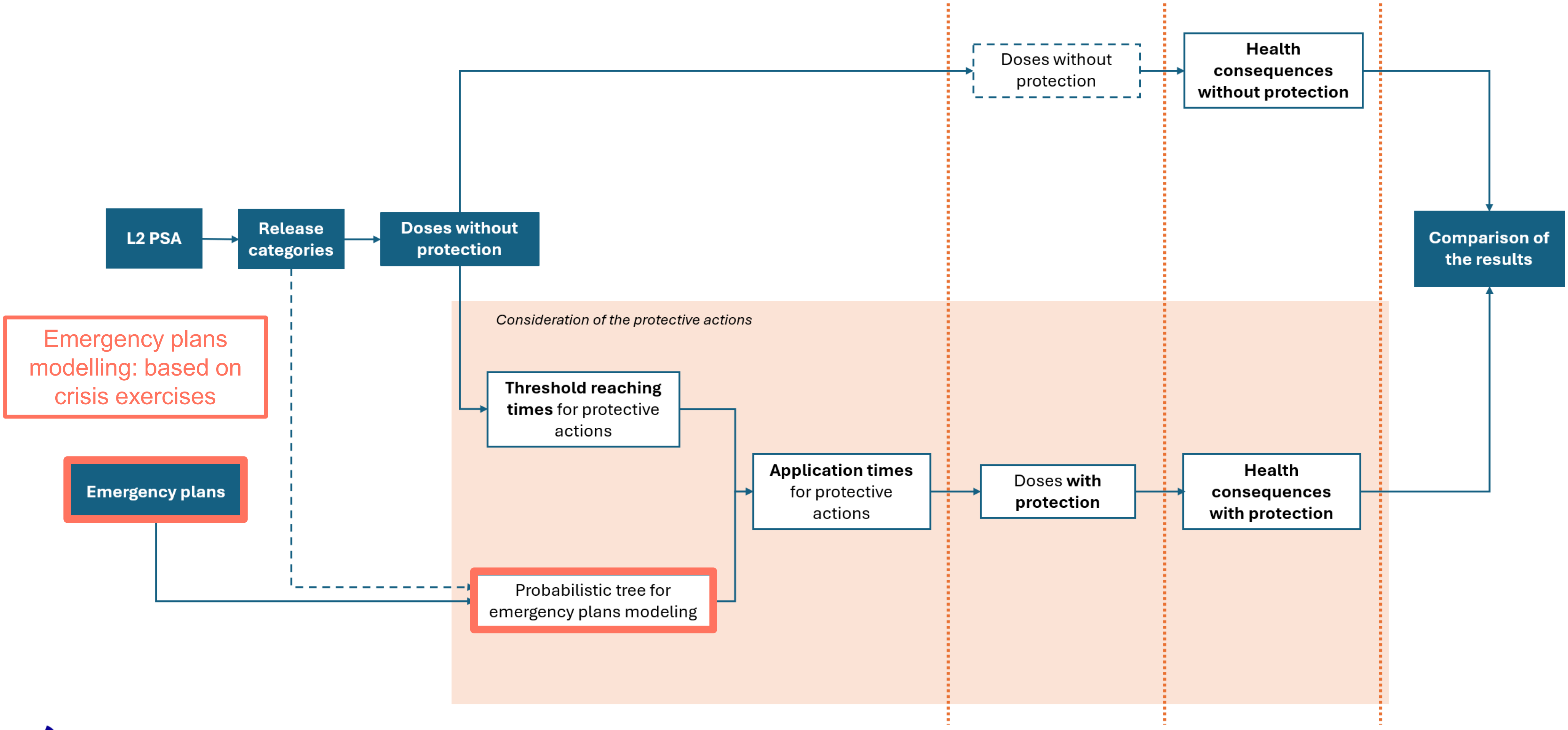
*Standard weather conditions*
*(Constant wind speed, direction …)*



# 02

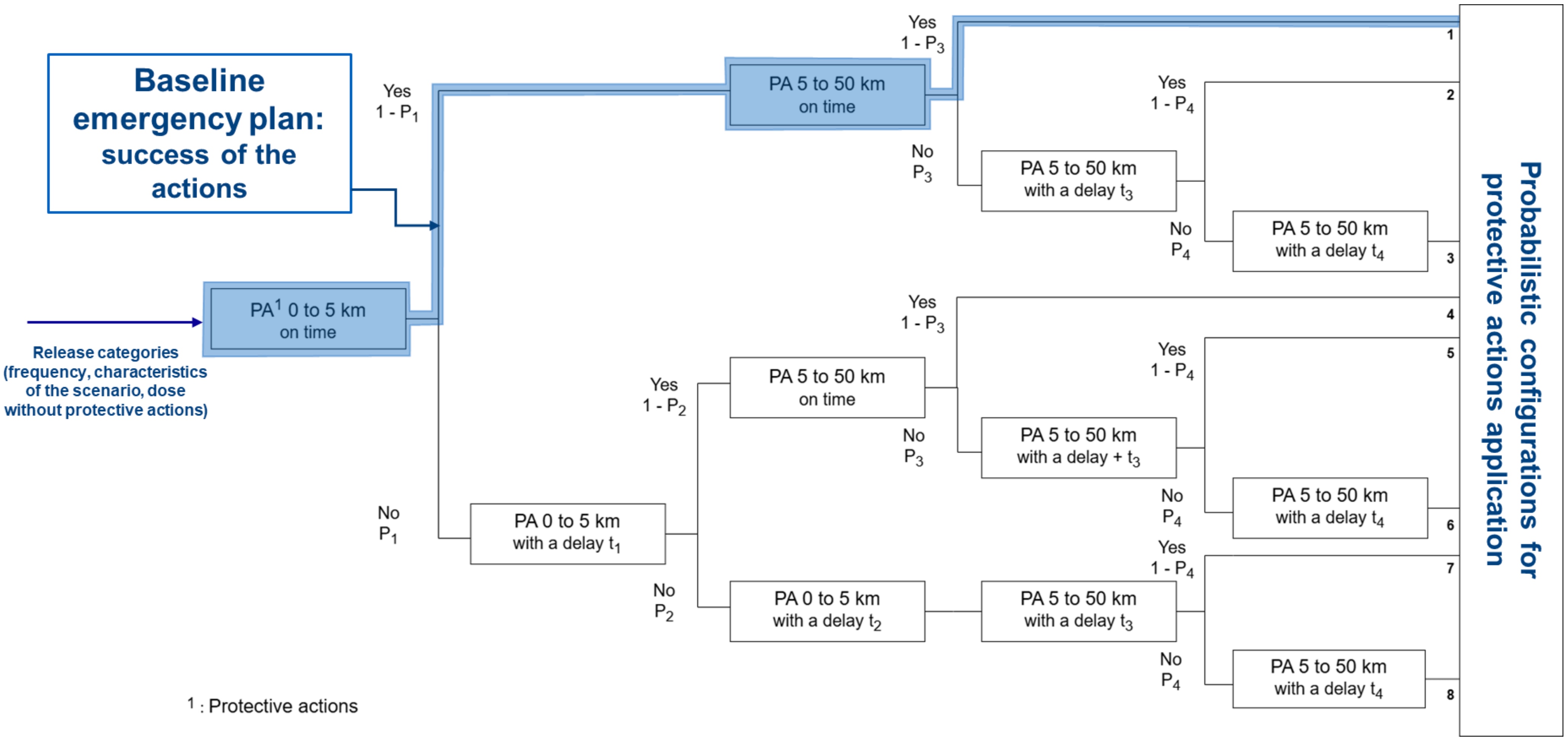
# TIMELINE MODELLING AND INPUT DATA

# PROBABILISTIC TREE



# PROBABILISTIC TREE

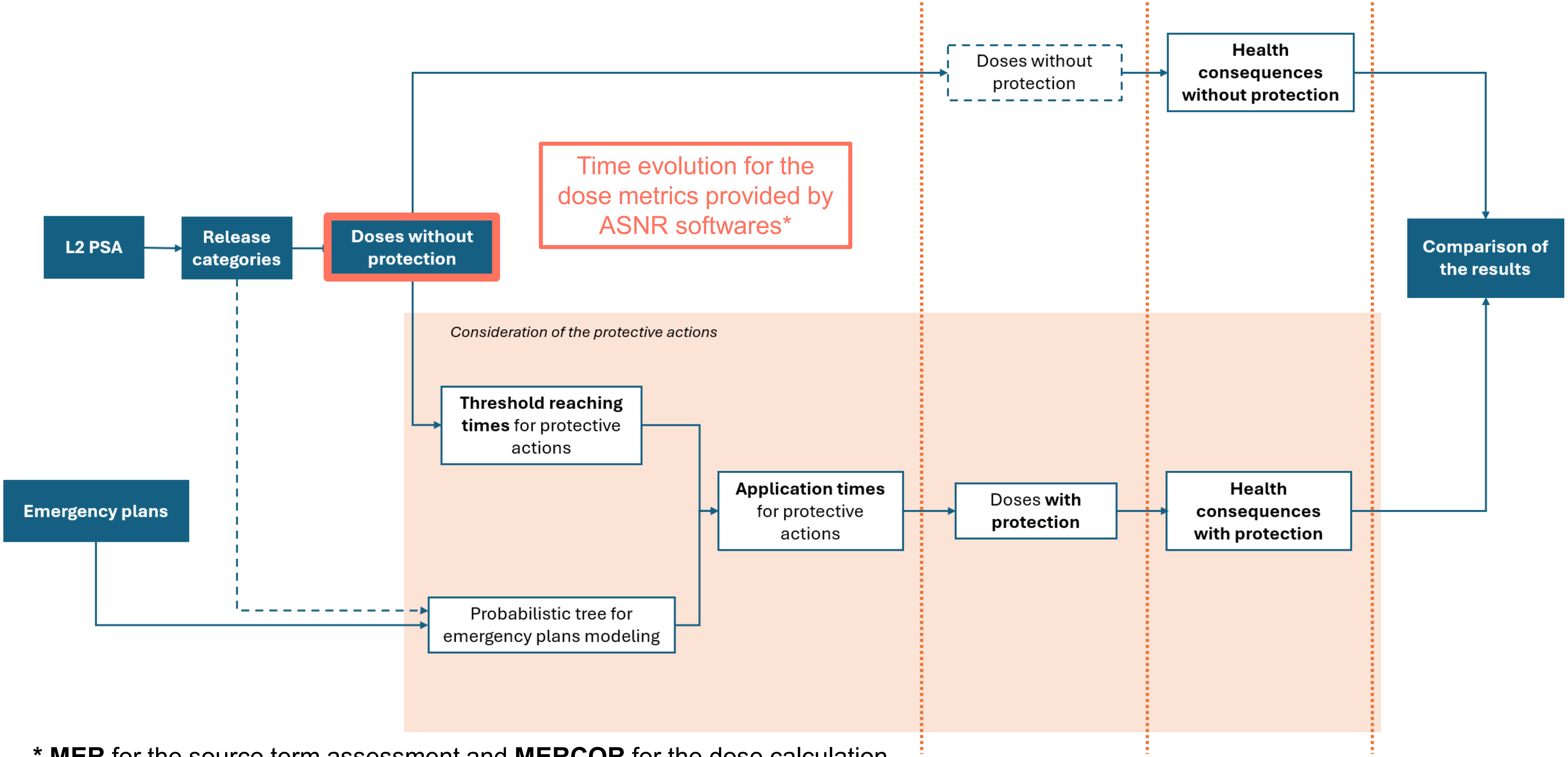
- Consideration of delays ($t_1$, $t_2$, $t_3$, $t_4$) in the application of the protective actions with a set of probabilities ($P_1$,$P_2$,$P_3$,$P_4$)




1 : Protective actions

**$P_1$ to $P_4$ and $t_1$ to $t_4$ will be defined by crisis exercises feedback analysis depending on release activity, accident kinetics…**

# DATA PROVIDED BY THE SOFTWARE MERCOR



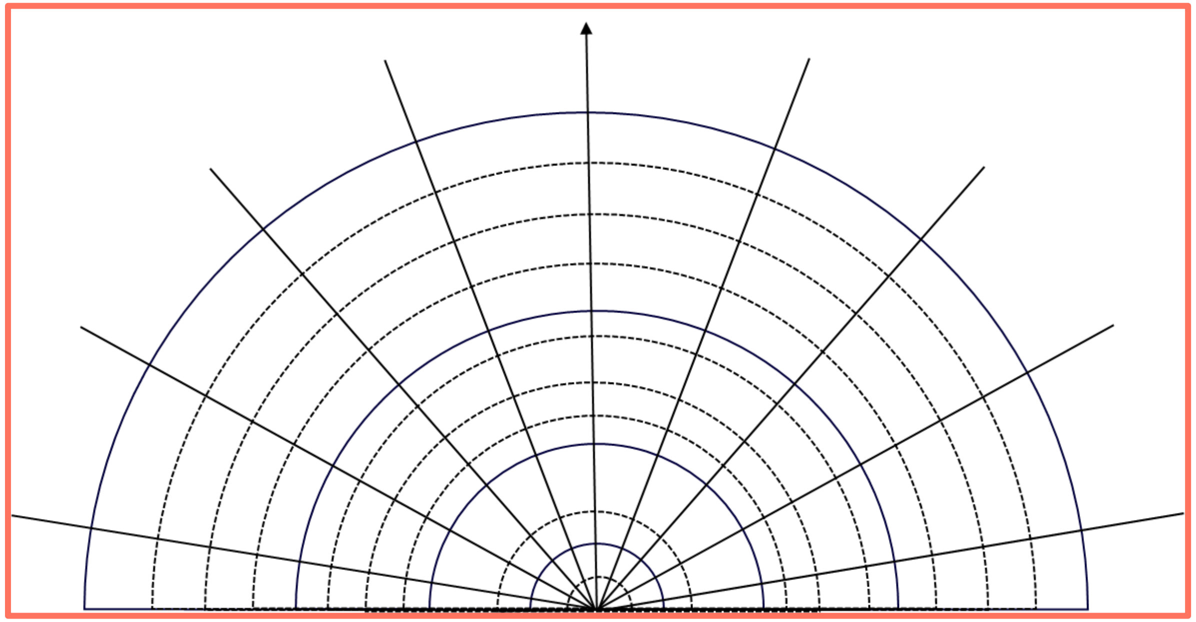

* **MER** for the source term assessment and **MERCOR** for the dose calculation

# DATA PROVIDED BY THE SOFTWARE MERCOR

## FOR A FIXED WIND DIRECTION :

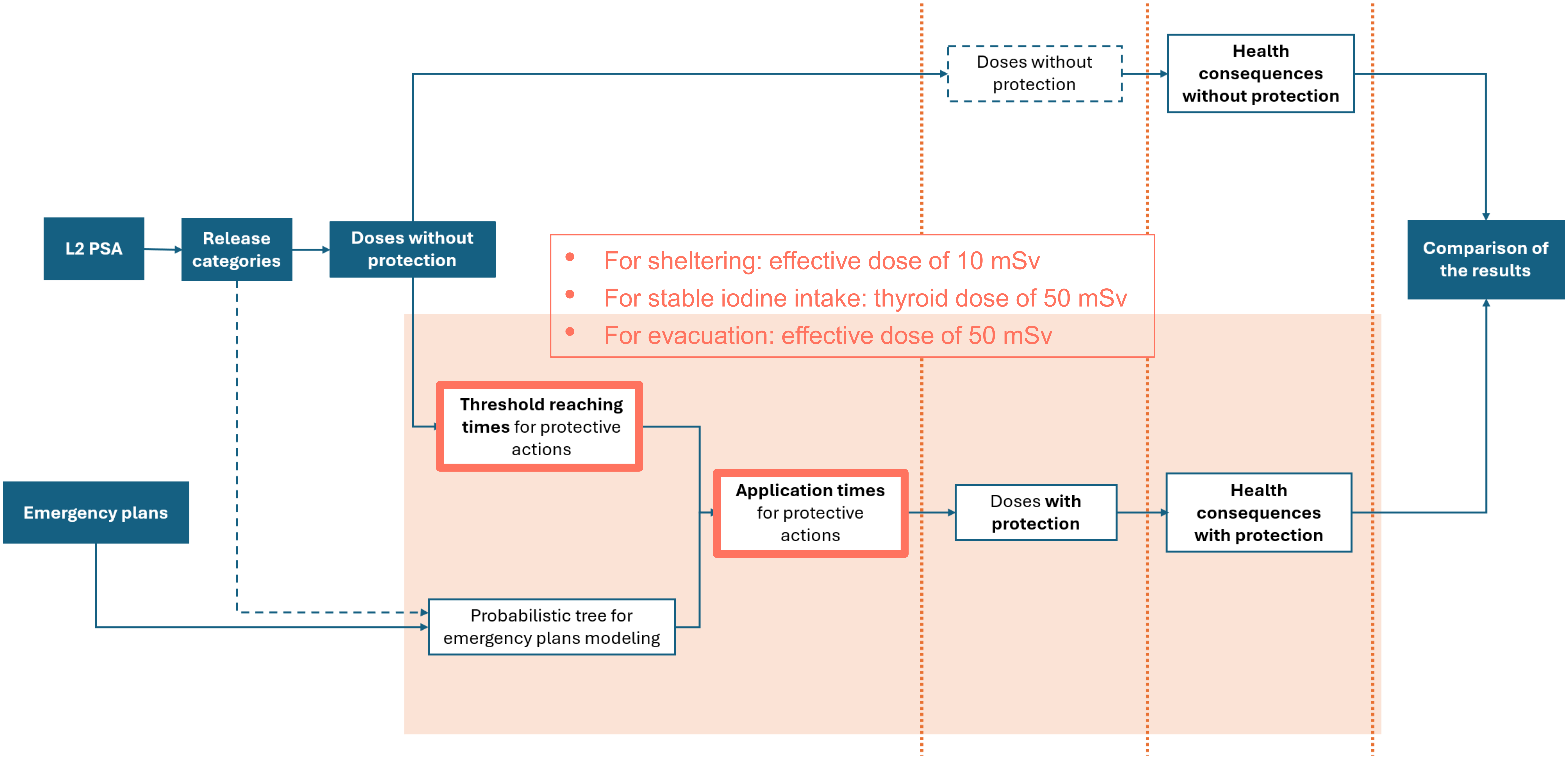
- Time evolution for the whole body effective dose and for the equivalent doses of the following organs:
  - Thyroid
  - Lungs (development in progress)
  - Breasts (development in progress)
  - Red bone marrow (development in progress)

- Time evolution for the dose contribution ratios for gas and iodine aerosols for each organ



GRID OF THE STUDIED ZONE

# TIMES OF APPLICATION FOR PROTECTIVE ACTIONS

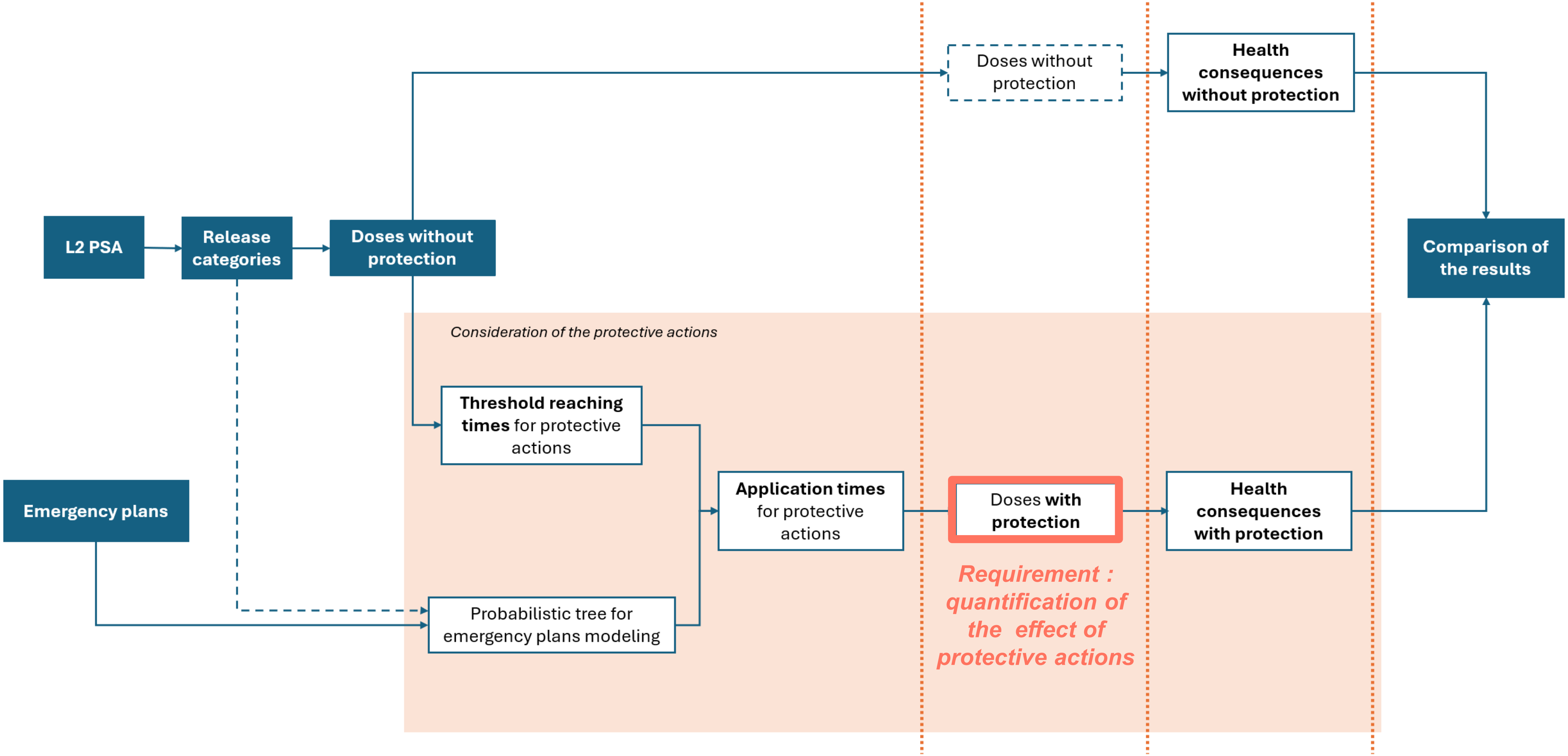



- For sheltering: effective dose of 10 mSv
- For stable iodine intake: thyroid dose of 50 mSv
- For evacuation: effective dose of 50 mSv

# 03

# PROTECTION FACTORS QUANTIFICATION

# CALCULATION OF DOSES WITH PROTECTION



# QUANTIFICATION OF PROTECTIVE ACTIONS EFFECTS

- **STABLE IODINE INTAKE**

(Saturation of the thyroid gland with stable iodine to prevent the fixation of radioactive iodine)

- **SHELTERING**

(Order to stay inside of a building)

The dose reduction effect is evaluated through **protection factors PF**:

$$PF(t) = \frac{D_{with\ sh\ or\ sii}(t)}{D_{without\ protection}(t)}$$

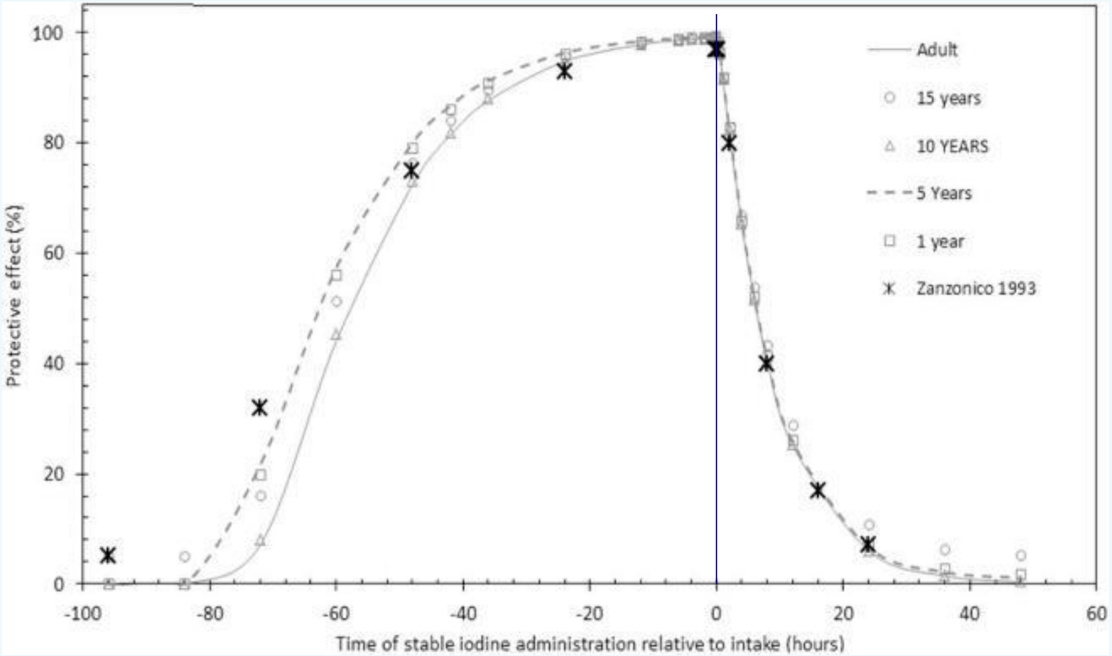
- **EVACUATION**

(Physical distancing from the release point)

Evaluation of the dose received during the evacuation : $D_{evac}$

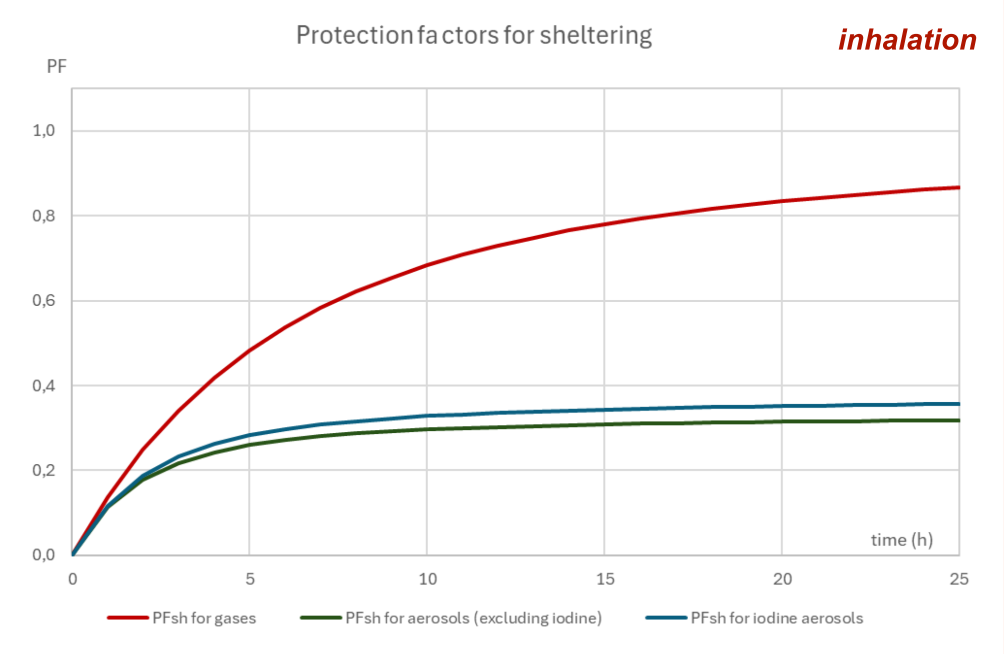
# PROTECTION FACTORS

## FOR PROTECTION BY STABLE IODINE INTAKE[1]




- Stable iodine intake only impacts the **thyroid dose received by inhalation**
- Protection by stable iodine intake is retroactive → protection factor ≠1 before the intake

## FOR PROTECTION BY SHELTERING




- For the **inhalation pathway**, $PF(t, \lambda_t, \lambda_d)$
- For the **cloud pathway**, $PF = 0{,}1$
- For the **ground pathway**, $PF = 0{,}05$

[1] D. Broggio, P. Teles, T. Verba and V. Berkovskyy. "*Assessment from in vivo measurements of thyroid dose due to iodine-131 inhalation when stable iodine has been administered*", Radiation Measurements, volume 127, (2019).

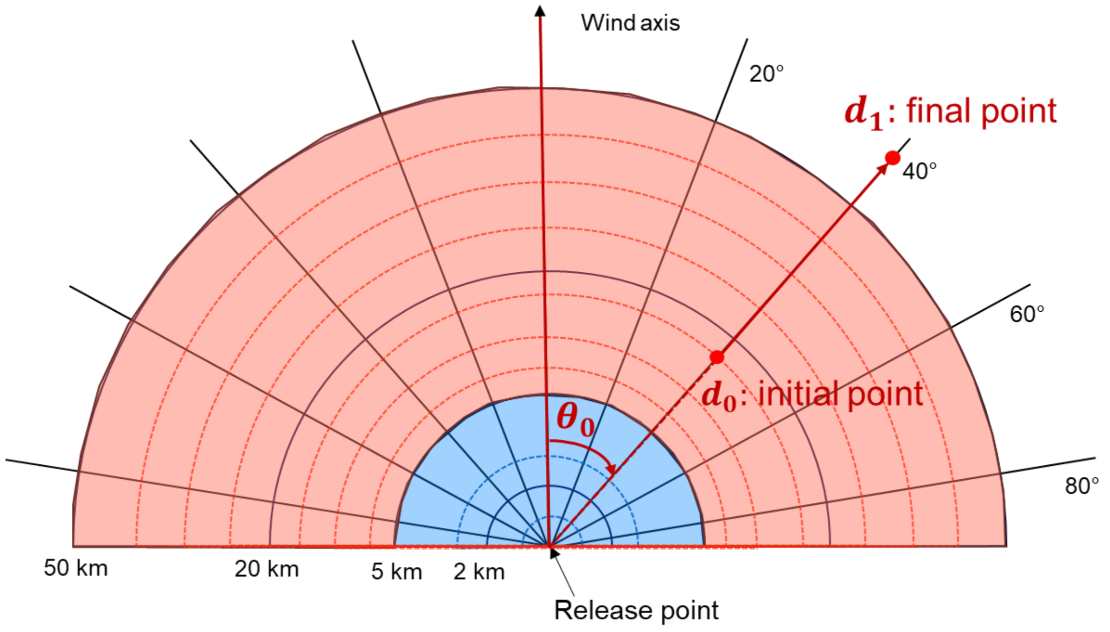
# EFFECT OF EVACUATION

- In case of evacuation :

$$D(t_1 \rightarrow t_2) = D(t_1 \rightarrow t_{evac}) + D_{evac}$$

- By **hypothesis**, the evacuation occurs in a **direct path** (straight line from the initial point, at a constant angle with the wind axis) and at **a constant speed**

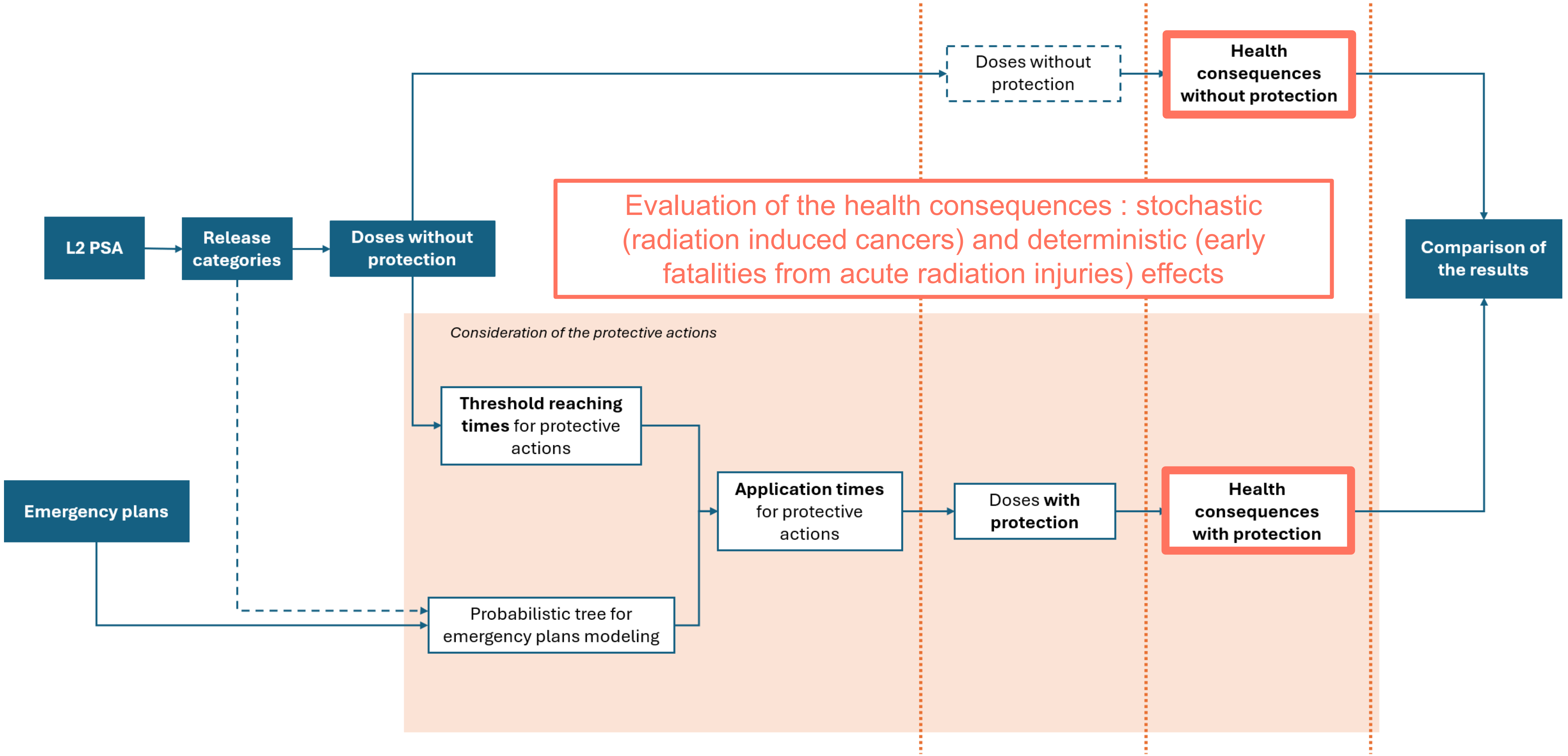
- **$D_{evac}$ is defined by extrapolating the dispersion model**



# 04

# CONSEQUENCES ASSESEMENT

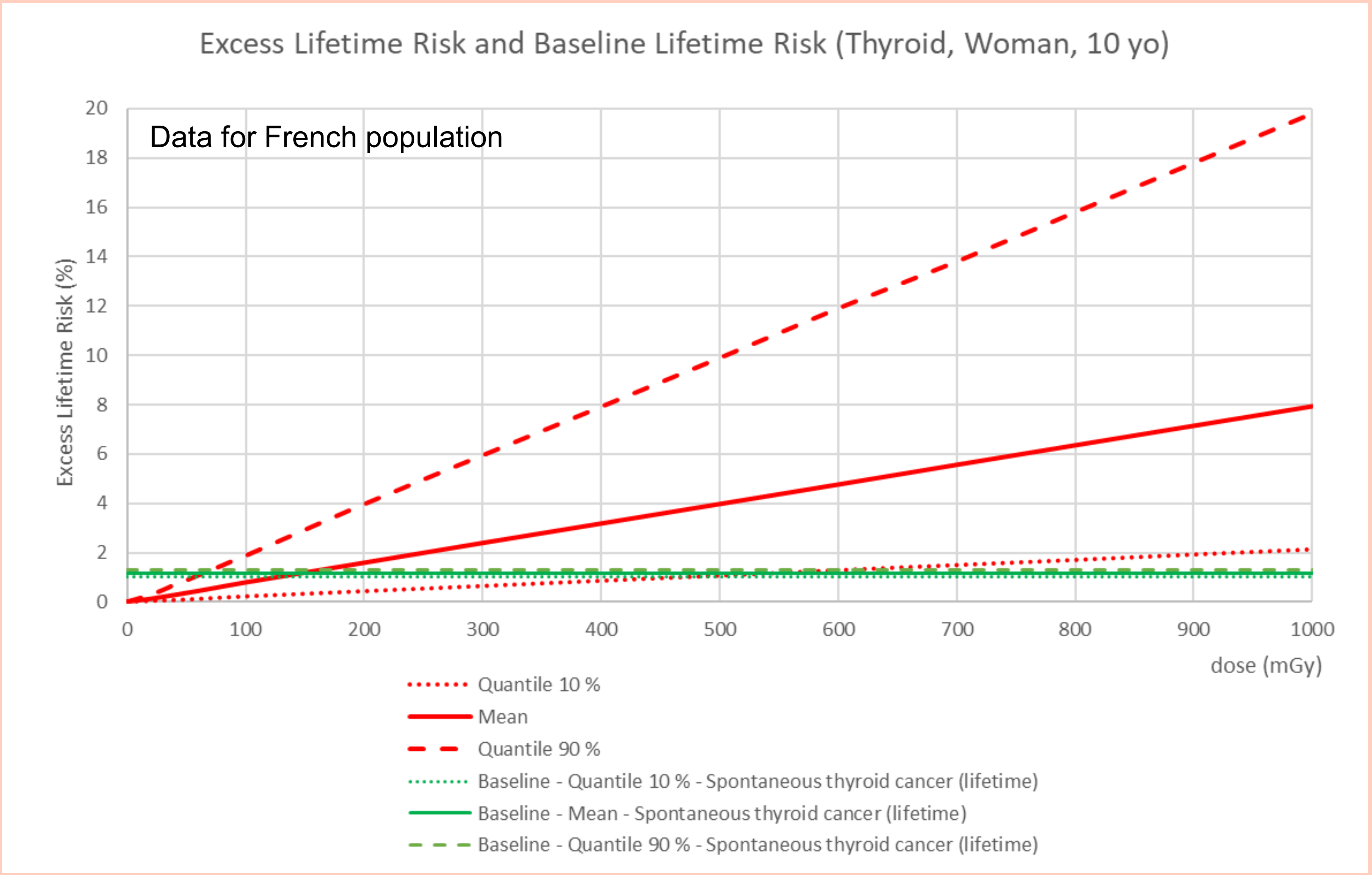
# HEALTH CONSEQUENCES EVALUATIONS



# STOCHASTIC HEALTH CONSEQUENCES

- Use of the **software tool RadRAT*** for the evaluation of the radiation induced cancers (for 4 organs - with or without protective actions)

- The consequences are evaluated as an **excess risk** and the approximation of **a number of individuals concerned**




* A. Berrington de Gonzalez et al. "*RadRAT: a radiation risk assessment tool for lifetime cancer risk projection*", Journal of Radiological Protection, volume 32, number 3, (2012).

# DETERMINISTIC HEALTH CONSEQUENCES

- Evaluation of a number of early fatalities

- The **exposure's lethality** is assessed for two organs:
  - **Lungs**
  - **Red bone marrow**

- The mortality law is defined as **a Weibull law,** function of the weighted absorbed dose that the organ received (Gy-eq)

$$\boxed{r = 1 - exp\left[-ln(2)\left[\left(\frac{D_1}{LD_{50}}\right)^{\nu_1} + \left(\frac{D_2}{LD_{50}}\right)^{\nu_2}\right]\right]}$$

# 05

# PERSPECTIVES AND CONCLUSIONS

# IN 2026 (FOR STANDARD METEOROLOGICAL CONDITIONS)

- Finalization of the probabilistic tree for protective actions application
- **Development of the model with the ASNR probabilistic software KANT* and interfacing with L2 PSA outputs**
- Sensitivity studies and results analysis

* See G. Bayle Ruault Des Courchamps, N. Rahni and E. Raimond. "*KANT, the ASNR probabilistic software for level 2 PSA*", PSAM18, 2026

# AFTER 2026 – SITE-SPECIFIC DATA

- **Realistic and site-specific data grids**
  - Population density for each NPP
  - Realistic meteorological variations

- **Main challenge**:
  - Data management

→ ~20 000 release scenarios,10 years of meteorological data

# THANK YOU FOR YOUR ATTENTION

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# APPENDICES

# A. EXAMPLE CASE FOR THE ORGAN THYROID

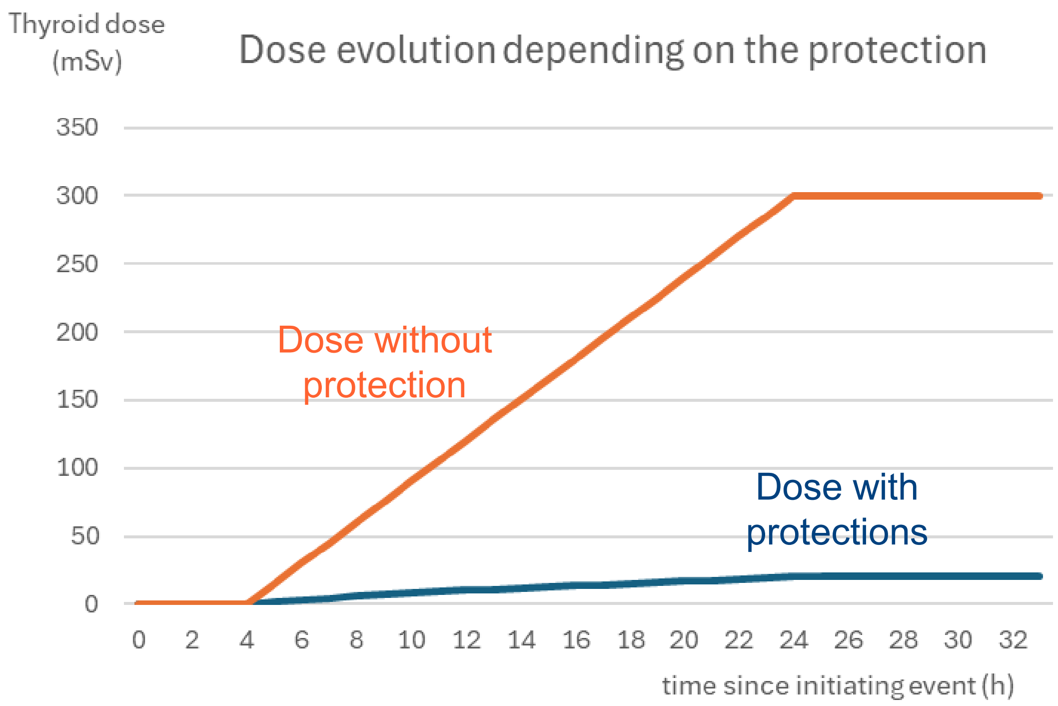
## THREE EXPOSURE PATHWAYS TO CONSIDER

- Inhalation: Protection by stable iodine intake and by sheltering (time-dependant protection factors)
- Ground: Protection by sheltering (constant value)
- Cloud: Protection by sheltering (constant value)

→ **SUM OF THE DOSE RECEIVED BY EACH PATHWAY**

→ **STOCHASTIC HEALTH CONSEQUENCES ASSESSMENT**

# A. EXAMPLE CASE FOR THE ORGAN THYROID




* Theoretical example for understanding:
- Gases and aerosols → 2 types of emission → 2 effects of protection
- assessed for a 5 year-old girl

## PROTECTIONS CONSIDERED :

- Sheltering 5 hours after the initiating event
- Stable iodine intake 12 hours after the initiating event (pessimistic scenario since the threshold is reached 4 hours before)

## DOSE-REDUCTION EFFECTS

- ~ 92 % reduction for the organ considered (hypothetical scenario)

## RISK DIMINUTION*

| | Without protection | With protection | Diminution |
|---|---|---|---|
| Excess risk | 3,6% | 0,2% | 94% |
| Total risk | 4,8% | 1,4% | 71% |

# B. GLOBAL APPROACH FOR ASNR L2+ AND L3 PSA