FUTURE INTEGRITY MANAGEMENT STRATEGY OF A GAS PIPELINE USING BAYESIAN RISK ANALYSIS

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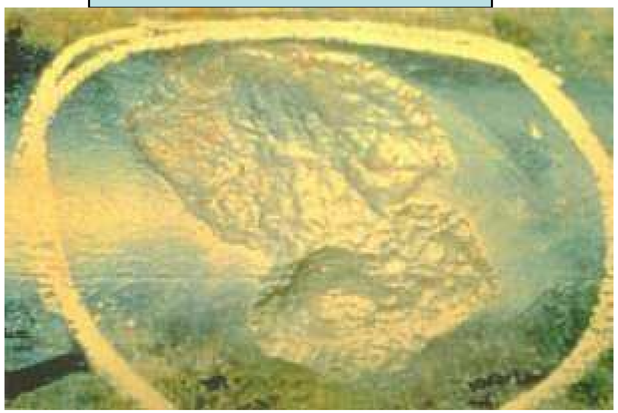
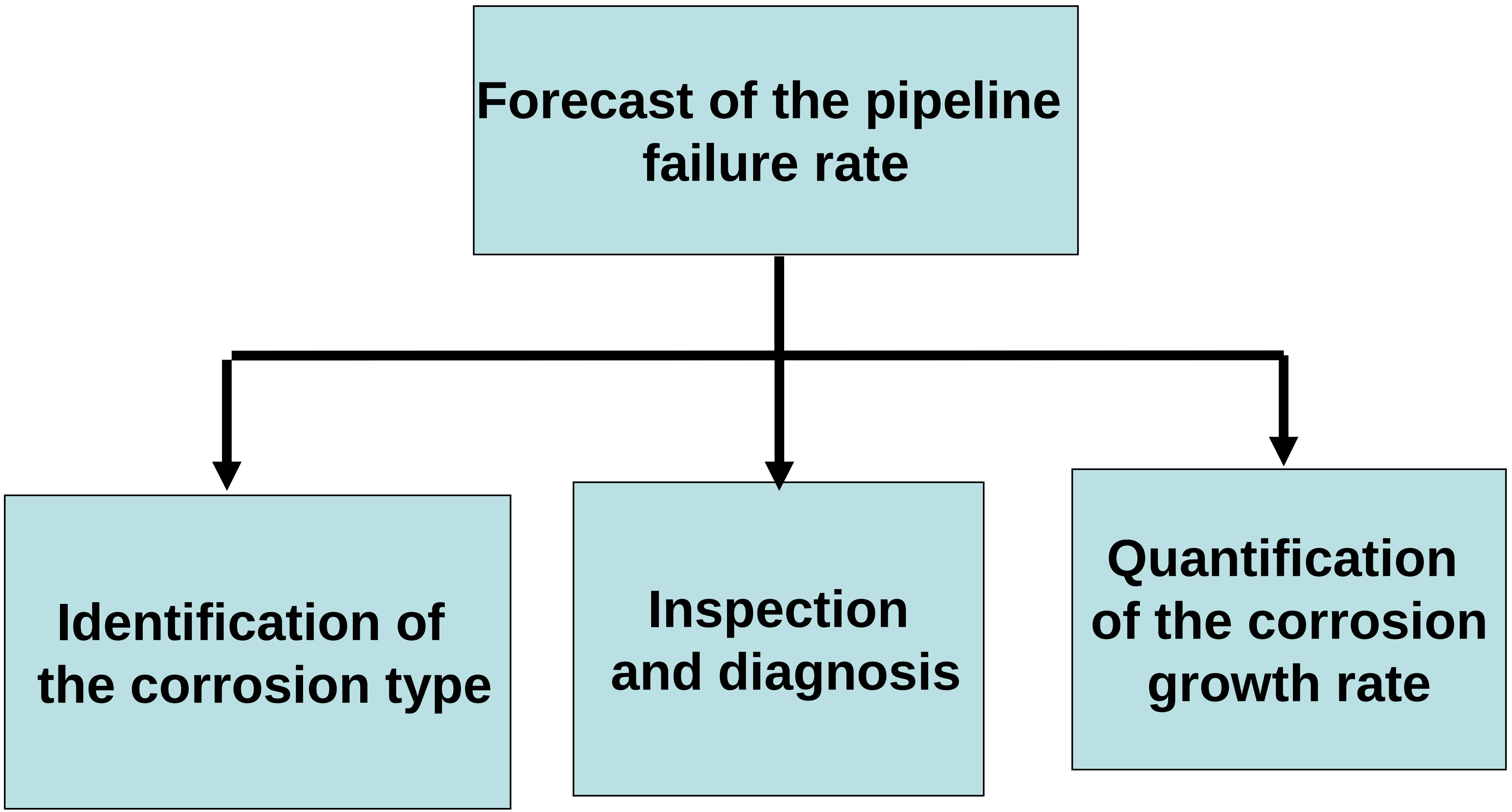
SONATRACH-ALGERIA

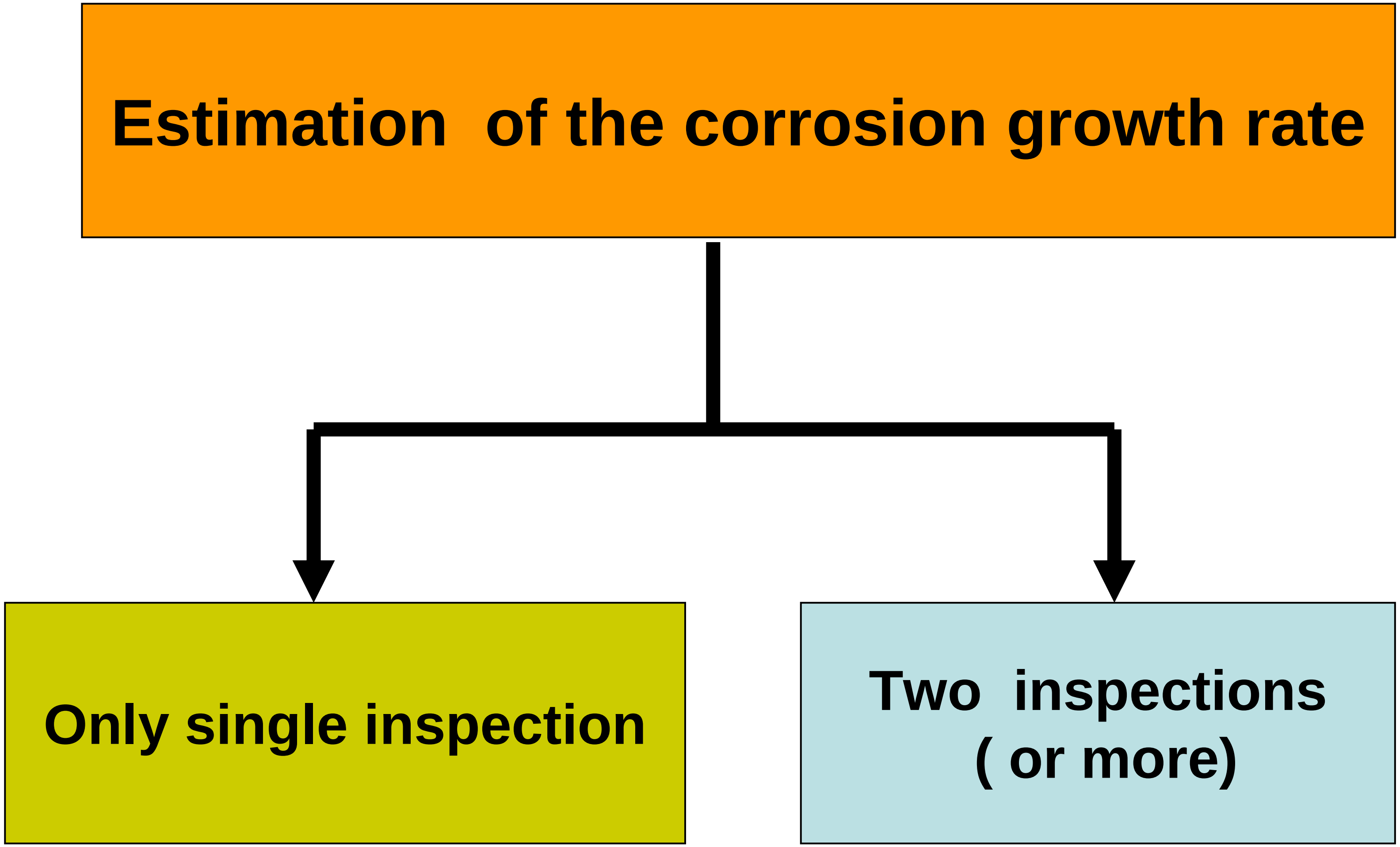
Pipeline Corrosion

Internal Corrosion

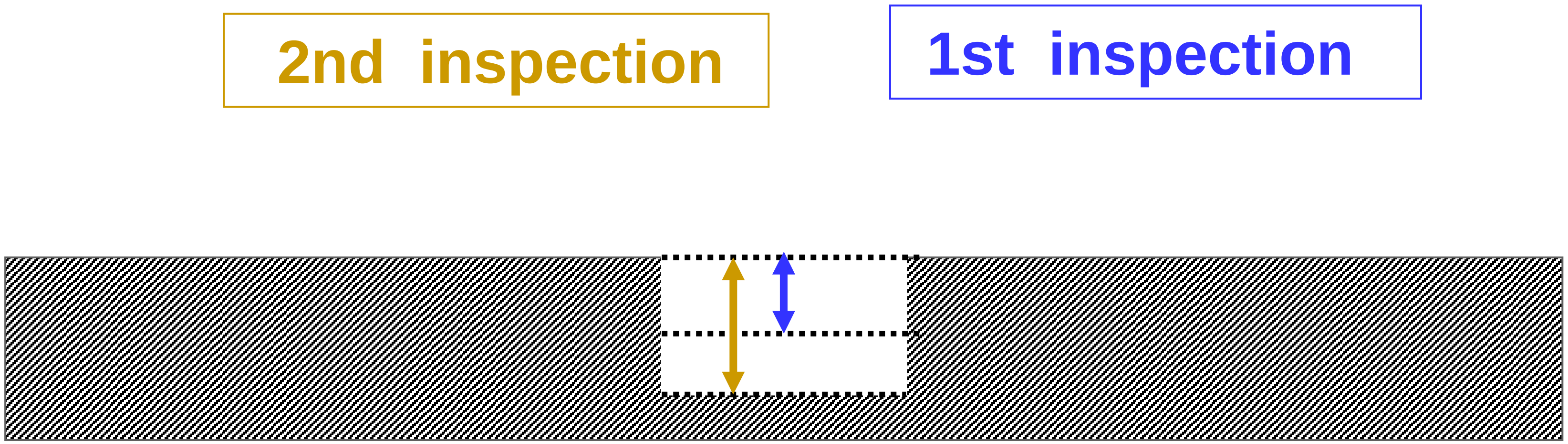
External Corrosion




Forecast of the pipeline failure rate
Identification of the corrosion type
Inspection and diagnosis
Quantification of the corrosion growth rate


Estimation of the corrosion growth rate
Only single inspection
Two inspections
(or more)

Evolution of corrosion depth between two inspections



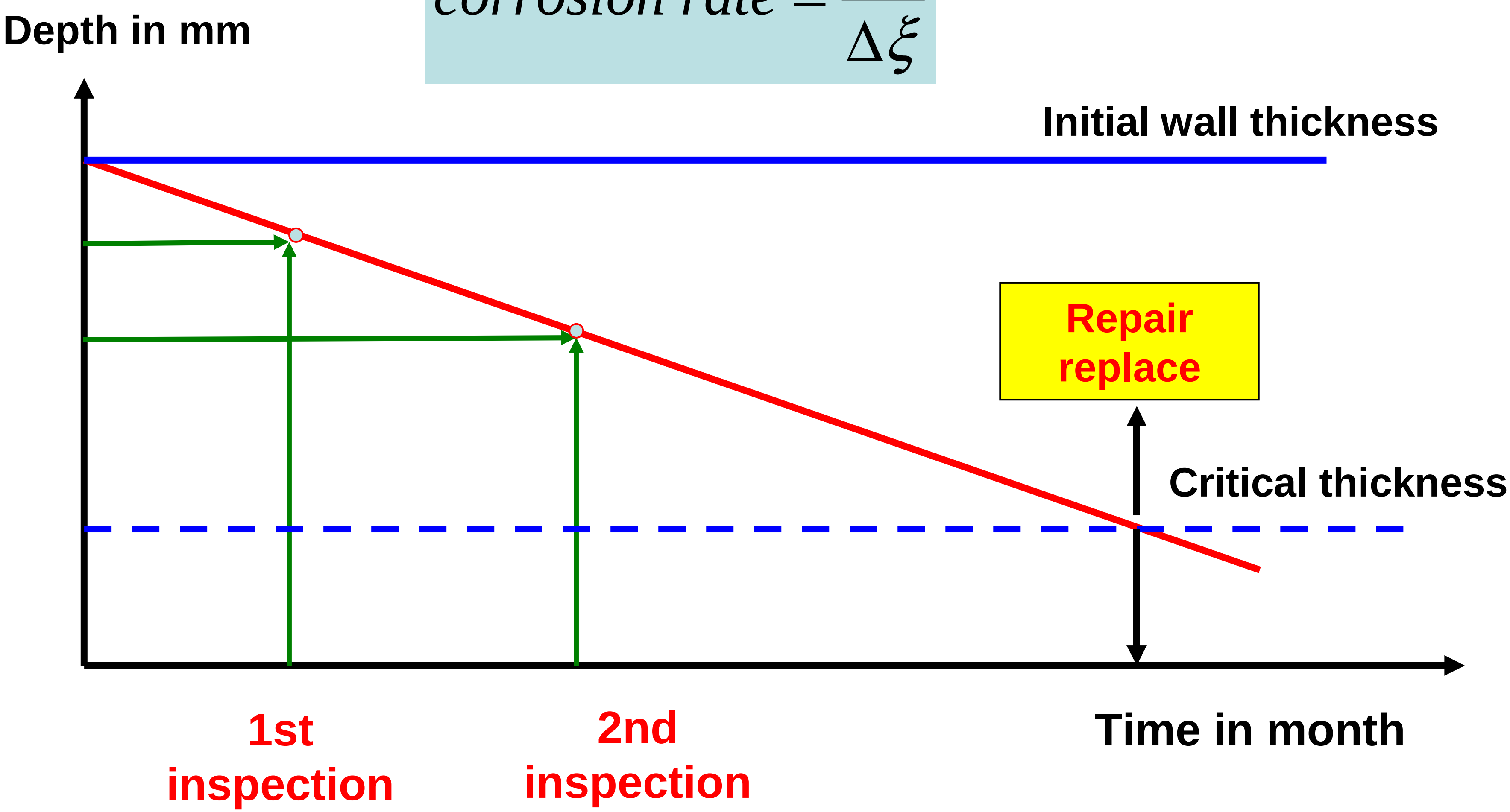
CASE OF TWO INSPECTIONS

- **Determinstic Approaches,**

- **Statistical Approaches.**

Determination of the corrosion growth rate (deterministic Case)

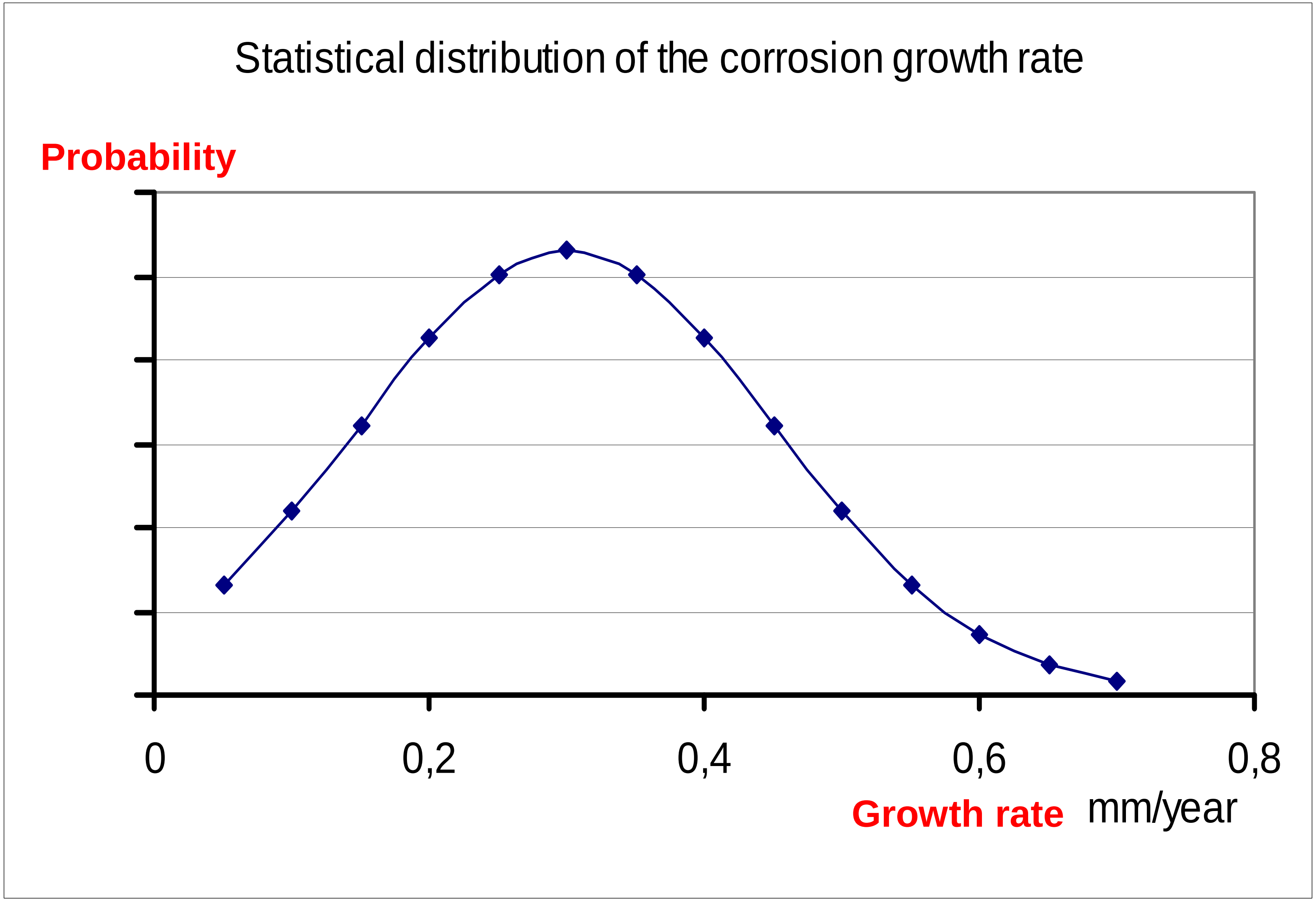
$$corrosion\ rate = \frac{\Delta d}{\Delta \xi}$$



Statistical analysis of the corrosion state

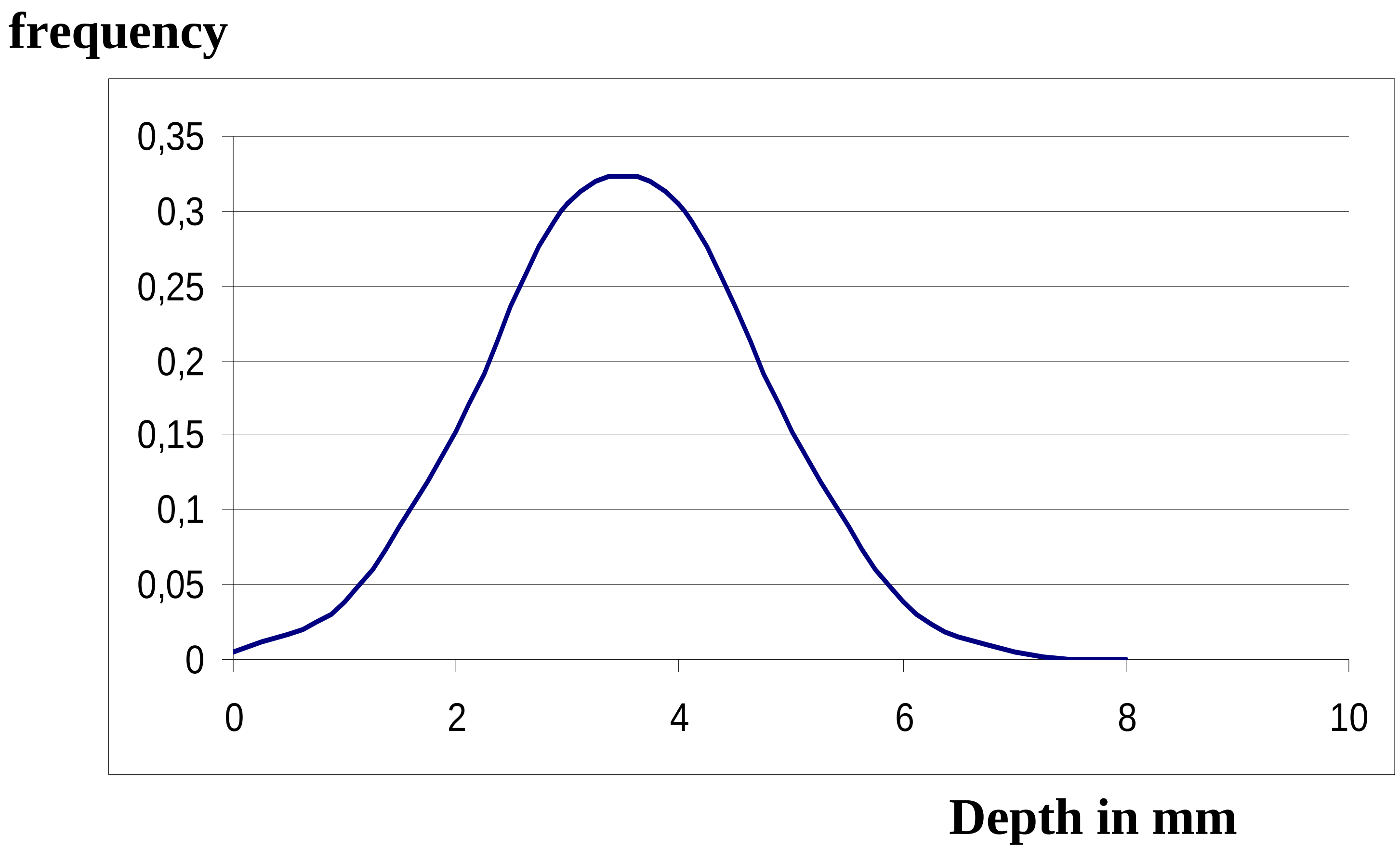
- In a corroded pipeline, each pipeleg can contain several hundreds of pits of different dimensions and forms.

- The assessment of the state of corrosion must then be done on the basis of statistical processing.

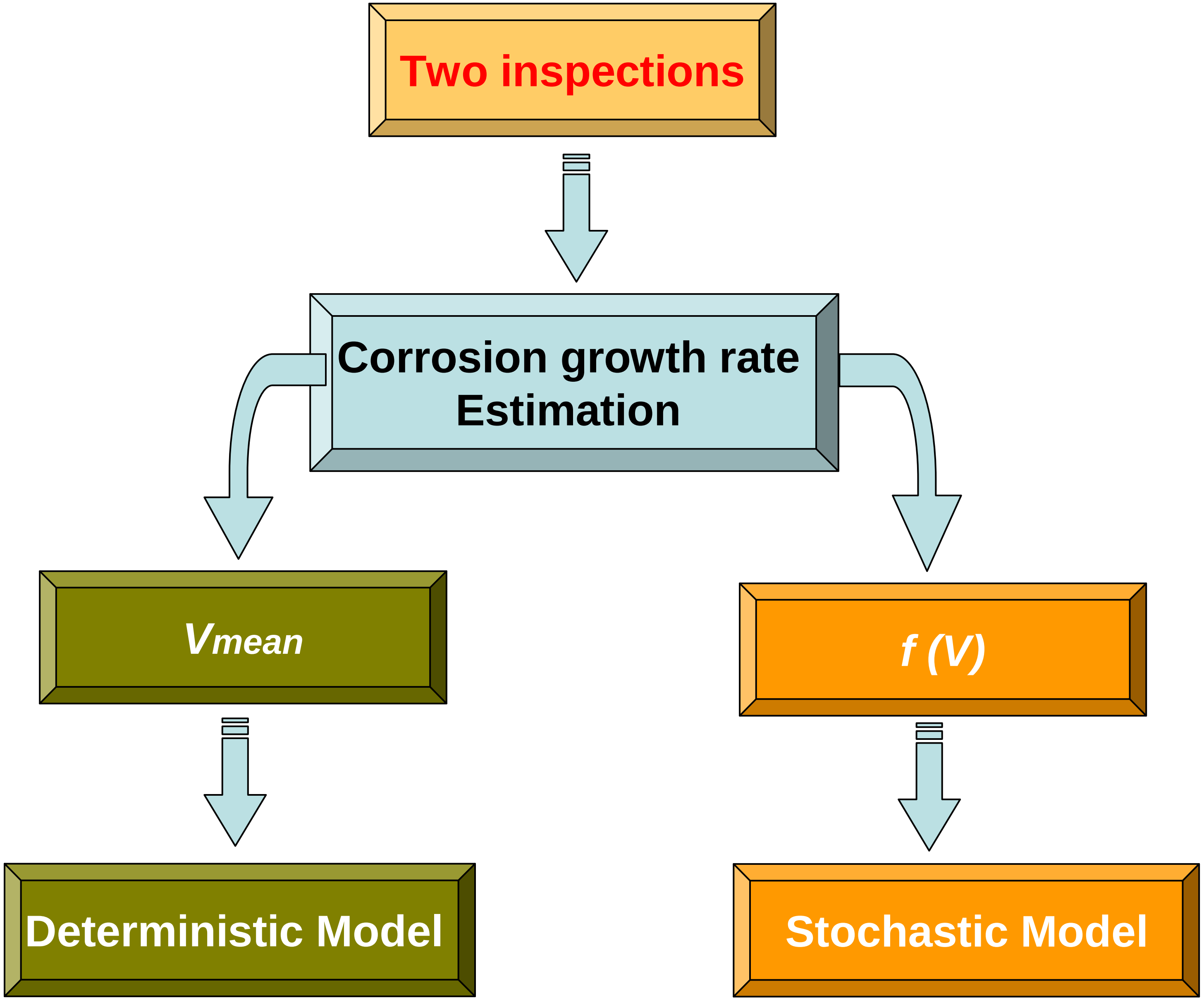


Statistical distribution of the corrosion growth rate
Probability
0
0,2
0,4
0,6
0,8
Growth rate
mm/year

Frequency of metal losses distribution



Usual Steps



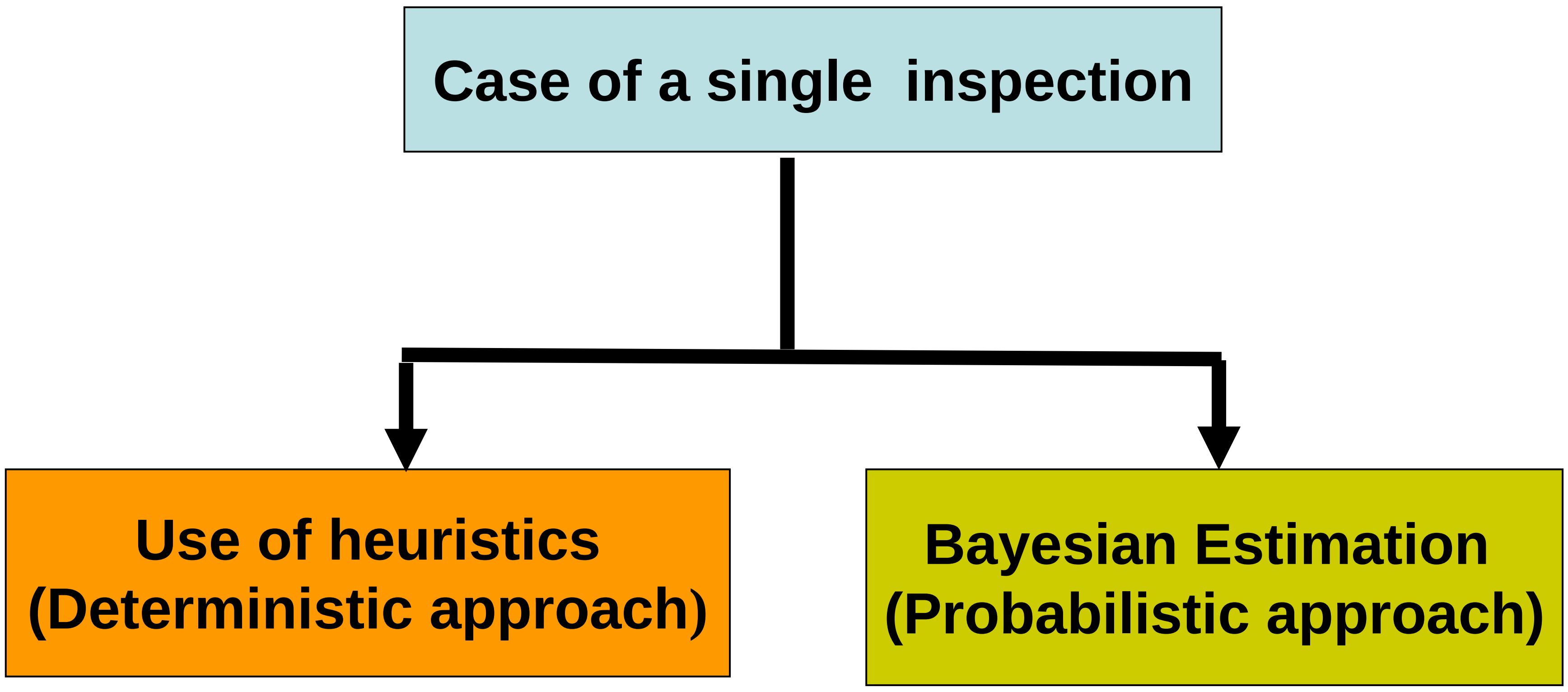
Two inspections
Corrosion growth rate Estimation
Vmean
f (V)
Deterministic Model
Stochastic Model

SINGLE INSPECTION

- The diagnostic by single inspection provides only one instantaneous image of the **state of degradation** of a pipeline

- How to obtain a sufficiently credible information on the dynamic of the degradation of a pipeline on the basis of a single inspection ?

- How to withdraw **maximum** information from only **single** inspection ?


Case of a single inspection
Use of heuristics
(Deterministic approach)
Bayesian Estimation
(Probabilistic approach)

Diagnosis and maintenance

- In-line inspection then the diagnosis, can almost provide all necessary information for the evaluation of the technical state of a pipeline.

- However, the care is left to the operators to decide the choices to make to maintain the pipeline in good condition.

Presentation of the inspection results

- An operation of inspection is included in theory in a global programme of diagnosis and maintenance of the gas pipeline.

- The results must thus be presented in a form allowing a direct interpretation by the services of maintenance.

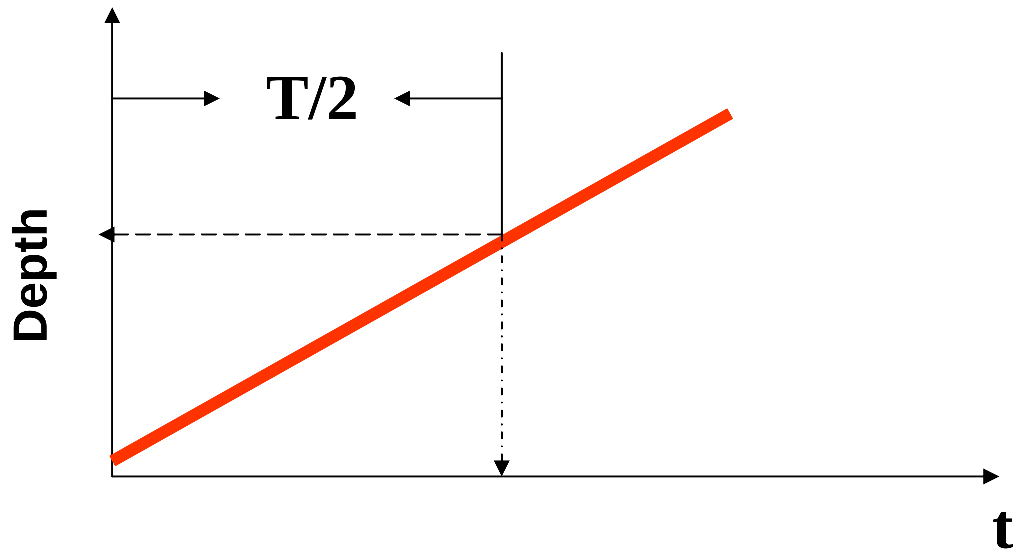
- The estimation of the corrosion growth rate on the basis of single inspection would theoretically require the knowledge of the **date** of **beginning** of corrosion of **each** point.

DETERMINISTIC APPROACH WITH USE OF HEURISTICS

- To consider that corrosion started as the putting on stream of the pipeline

- corrosion started at the moment **T/2**,

- A the **T=0** moment the depths of corrosion are null



- **R**aw extrapolation of data resulting from pipelines having undergone **several** inspections

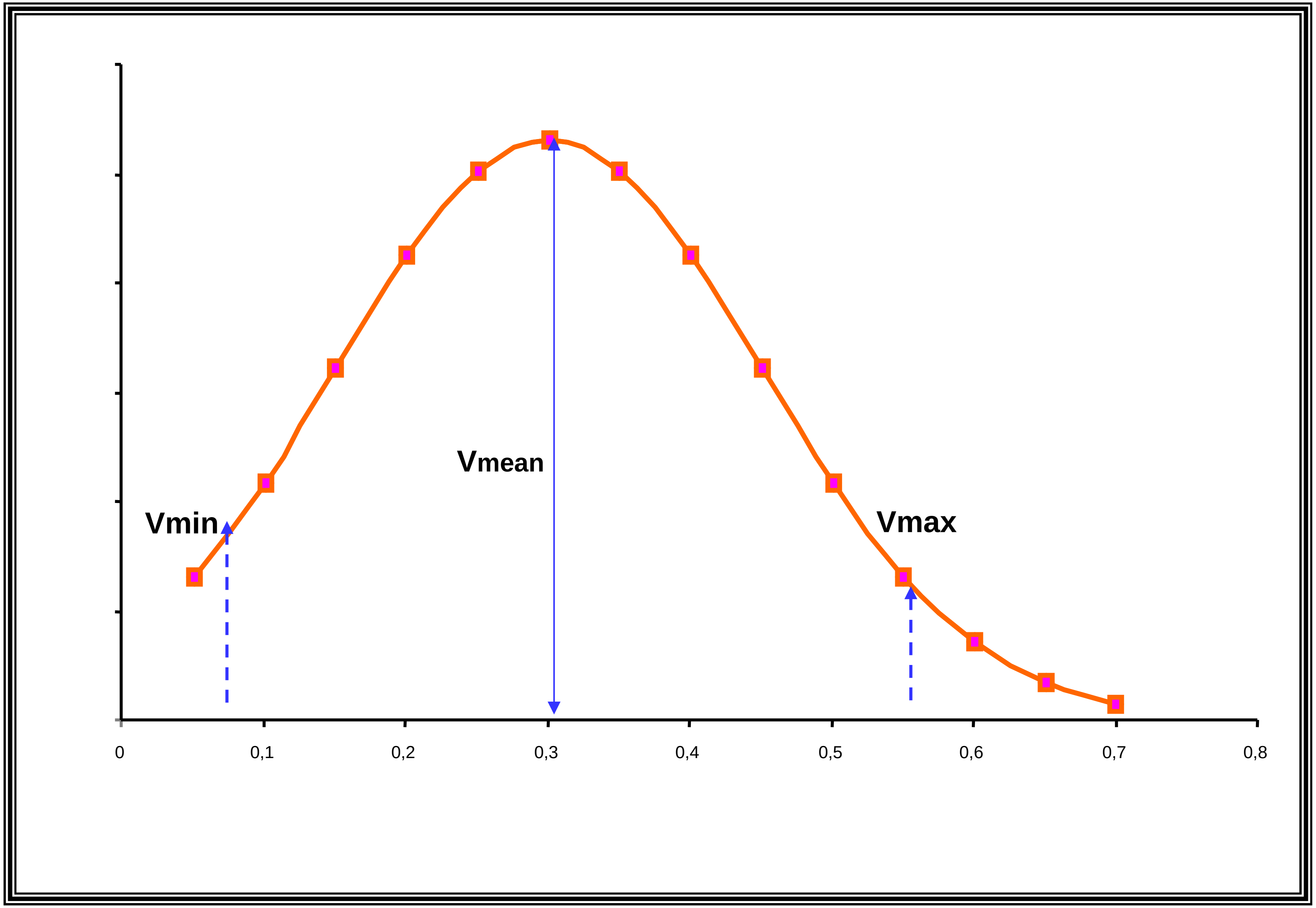
BAYESIAN APPROACH OF THE CORROSION GROWTH RATE ESTIMATION

The principle of this method consists in associating :

- Information on the corrosion growth rate, acquired on other pipelines, (Vmin et Vmax);

- Real data on the corrosion depths obtained during a single inspection.

PRIOR DISTRIBUTION OF THE CORROSION GROWTH RATE



Gamma Law

$$f(V,\beta_0,\theta_0)=\frac{\theta_0^{\ \beta_0}}{\Gamma(\beta_0)}V^{\beta_0-1}Exp(-V\theta_0)$$

V : **Corrosion growth rate**

θ_0 : **Scale parameter**

β_0 : **Shape parameter**

Determination of the Prior distribution of the corrosion growth rate

1. Choice of a **Prior Gamma** distribution of the corrosion growth rate **modeling** the available information (expressed in the form of **interval**).

2. Correction of those intervals:

$$V_{\min} = \frac{d_{avr}}{T-1} \geq V_{\min\_b}$$

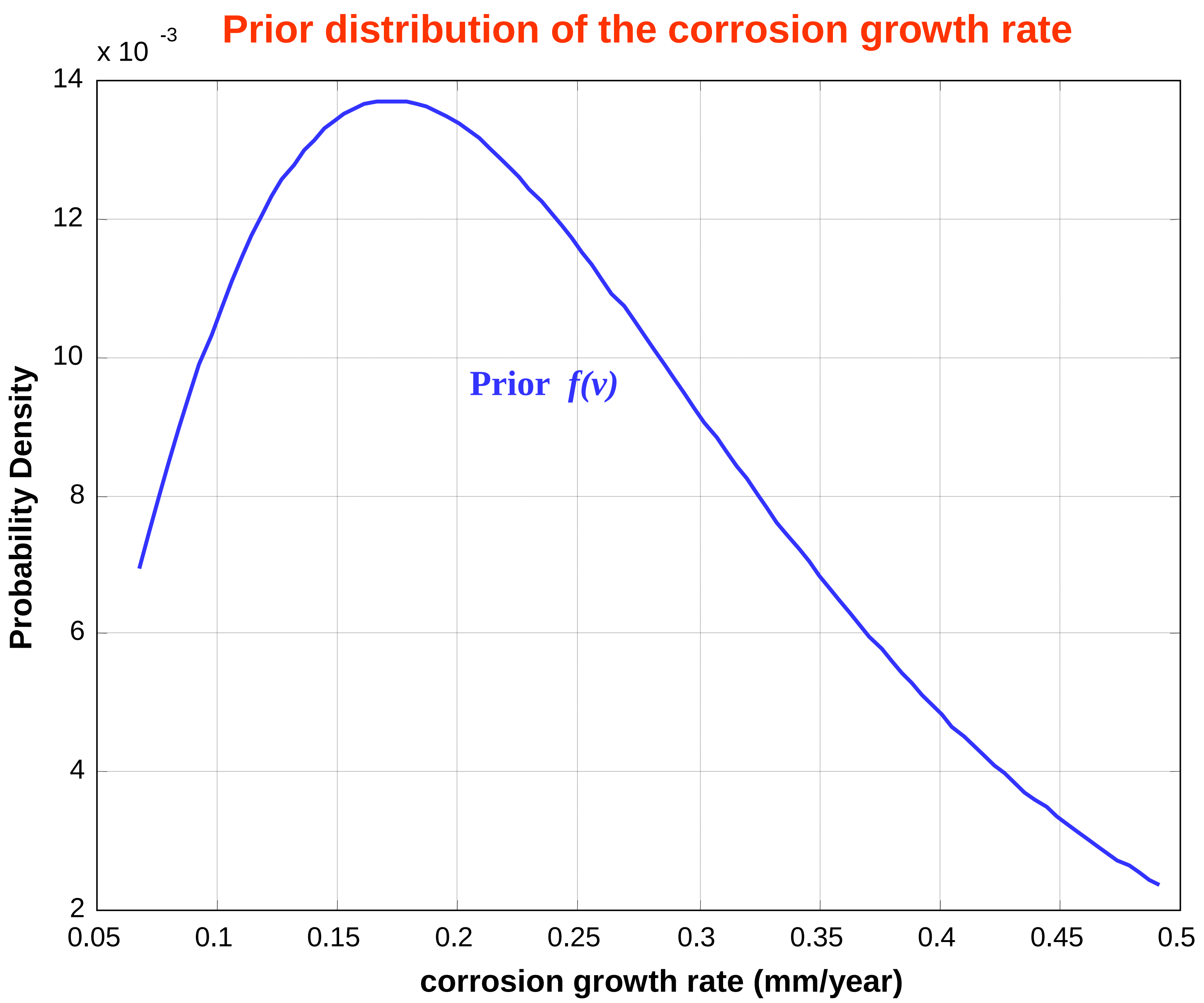
$$V_{\max} = \frac{d_{avr}}{1} \leq V_{\max\_b}$$

3. Identification of parameters β_0 and θ_0 of the prior Gamma distribution

$$\left(\left(\sum_{i=1}^{n} f(V_i)\cdot \Delta x_i\right)-0{,}05\right)^2+\left(\left(\sum_{i=1}^{n} f(V_i)\cdot \Delta x_i\right)-0{,}95\right)^2 \Rightarrow Min$$

4. To express the prior corrosion growth rate by the relation :

$$f(V)=\frac{\theta_0}{\Gamma(\beta_0)}\cdot V^{(\beta_0-1)}\cdot Exp(\theta_0\cdot V)$$



Prior distribution of the corrosion growth rate
x 10 -3
14
12
10
8
6
4
2
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Probability Density
corrosion growth rate (mm/year)
Prior f(v)

Estimation of the most probable time of corrosion beginning

✓ In a homogeneous area of corrosion, the corrosion points are not judicious to appear at the same period.

Law of distribution of the durations of corrosion beginning

↓

Theory of the Functions of Random variable.

Functions of Random variable

$$f(V) \qquad \frac{\theta_0}{\Gamma(\beta_0)} \cdot V^{(\beta_0 - 1)} \cdot Exp(\theta_0 \cdot V)$$

$$\xi = \varphi(V) \qquad \xi = \frac{d_{avr}}{V}$$

$$V = \psi(\xi) \qquad V = \frac{d_{avr}}{\xi}$$

$$\psi'(\xi) \qquad = -\frac{d_{avr}}{\xi^2}$$

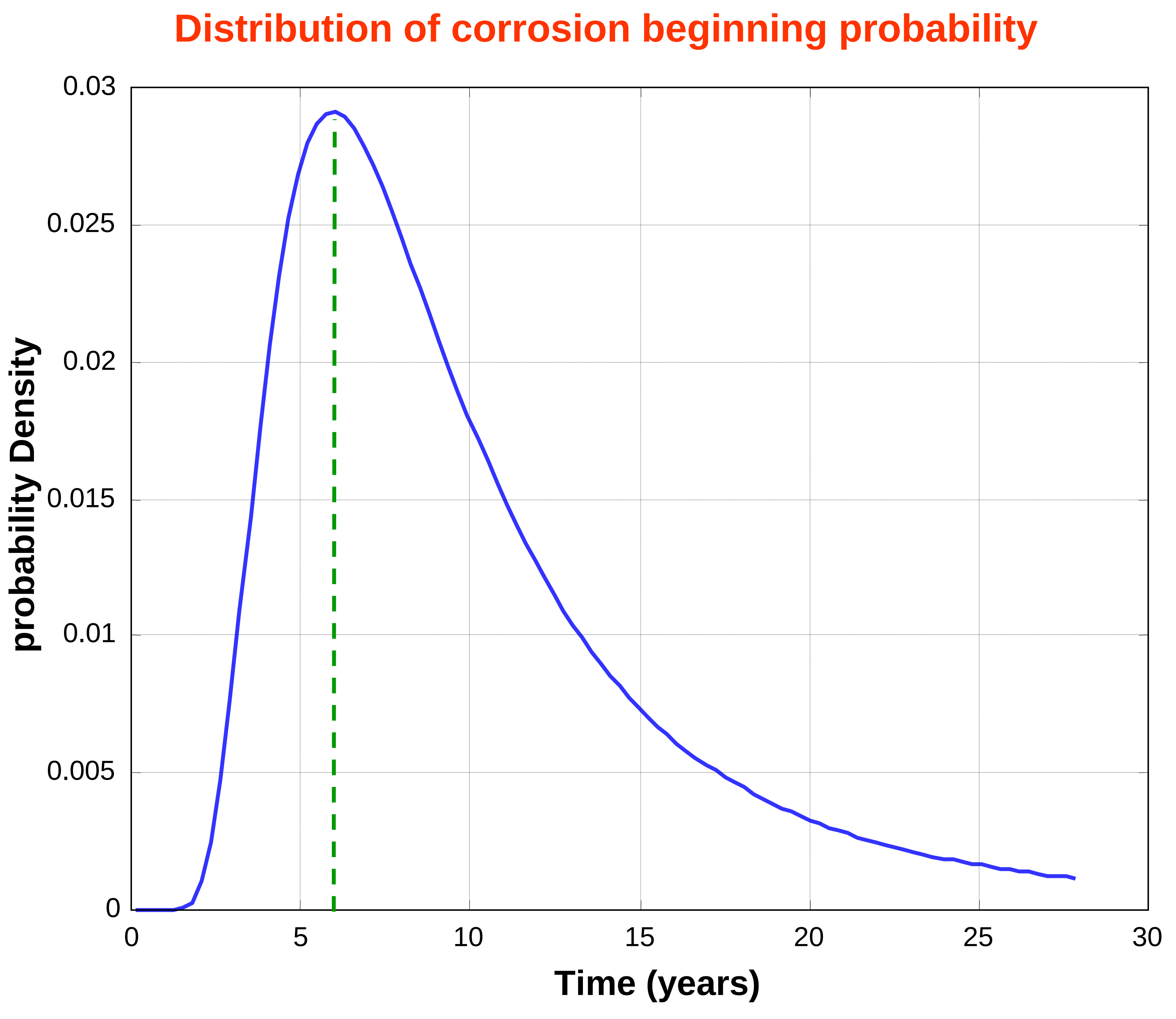
$$|\psi'(\xi)| \qquad = \frac{d_{avr}}{\xi^2}$$

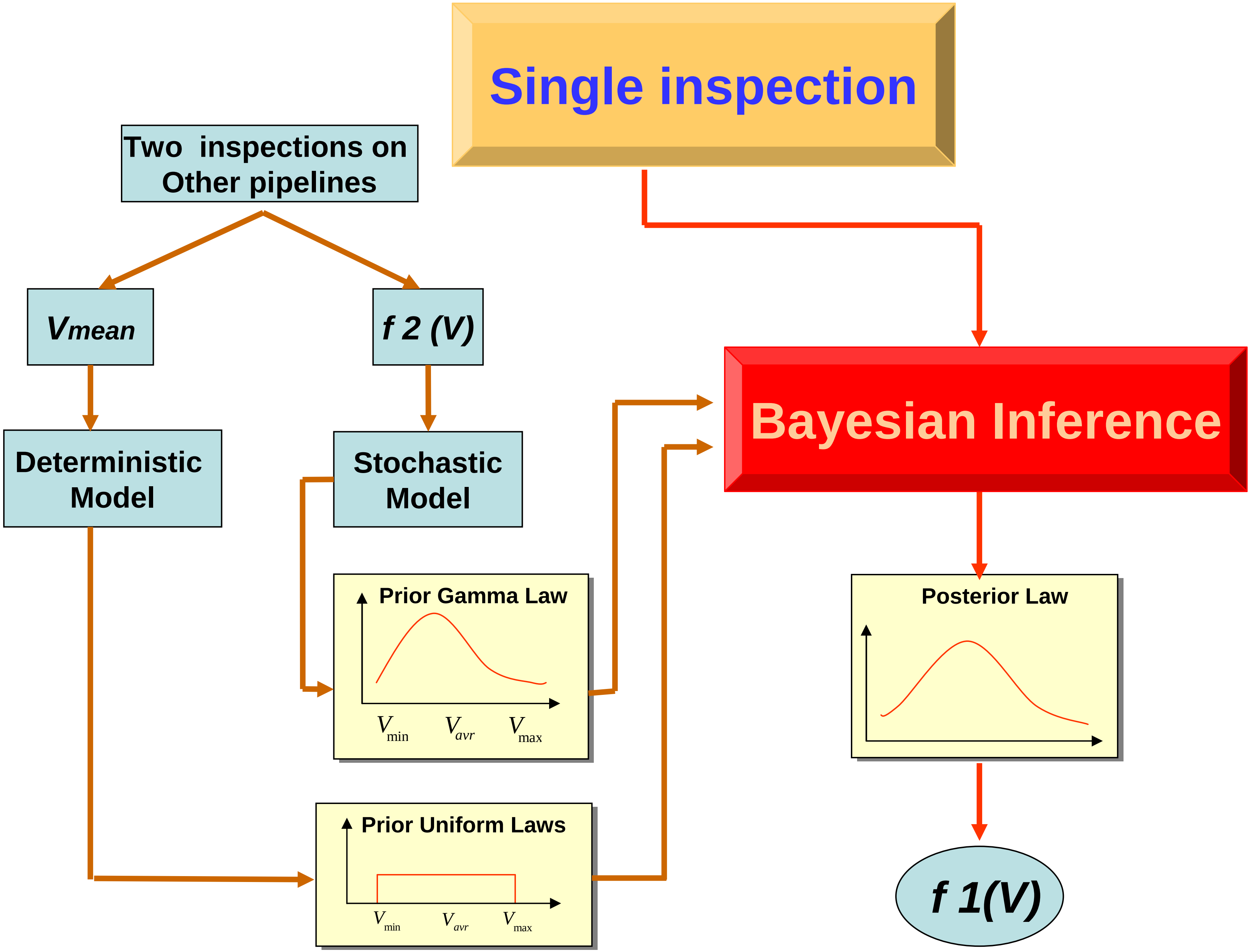
$$g(\tau) = f(\psi(\xi)) \cdot |\psi'(\xi)| \qquad = \frac{d_{avr}}{\xi^2} \frac{\theta_0}{\Gamma(\beta_0)} \cdot \left(\frac{d_{avr}}{\xi}\right)^{(\beta_0 - 1)} \cdot Exp\left(\theta_0 \cdot \frac{d_{avr}}{\xi}\right)$$

$$g(\xi) = \frac{d_{avr}}{\xi^2} \frac{\theta_0}{\Gamma(\beta_0)} \cdot \left(\frac{d_{avr}}{\xi}\right)^{(\beta_0 - 1)} \cdot Exp\left(\theta_0 \cdot \frac{d_{avr}}{\xi}\right)$$

To determine the most probable time of corrosion beginning we will use the following model of **optimization** :

$$\frac{d_{avr}}{\xi^2}\frac{\theta_0}{\Gamma(\beta_0)}\cdot\left(\frac{d_{avr}}{\xi}\right)^{(\beta_0-1)}\cdot Exp\left(\theta_0\cdot\frac{d_{avr}}{\xi}\right)\Rightarrow Max$$


Distribution of corrosion beginning probability
0.03
0.025
0.02
0.015
0.01
0.005
0
probability Density
0
5
10
15
20
25
30
Time (years)



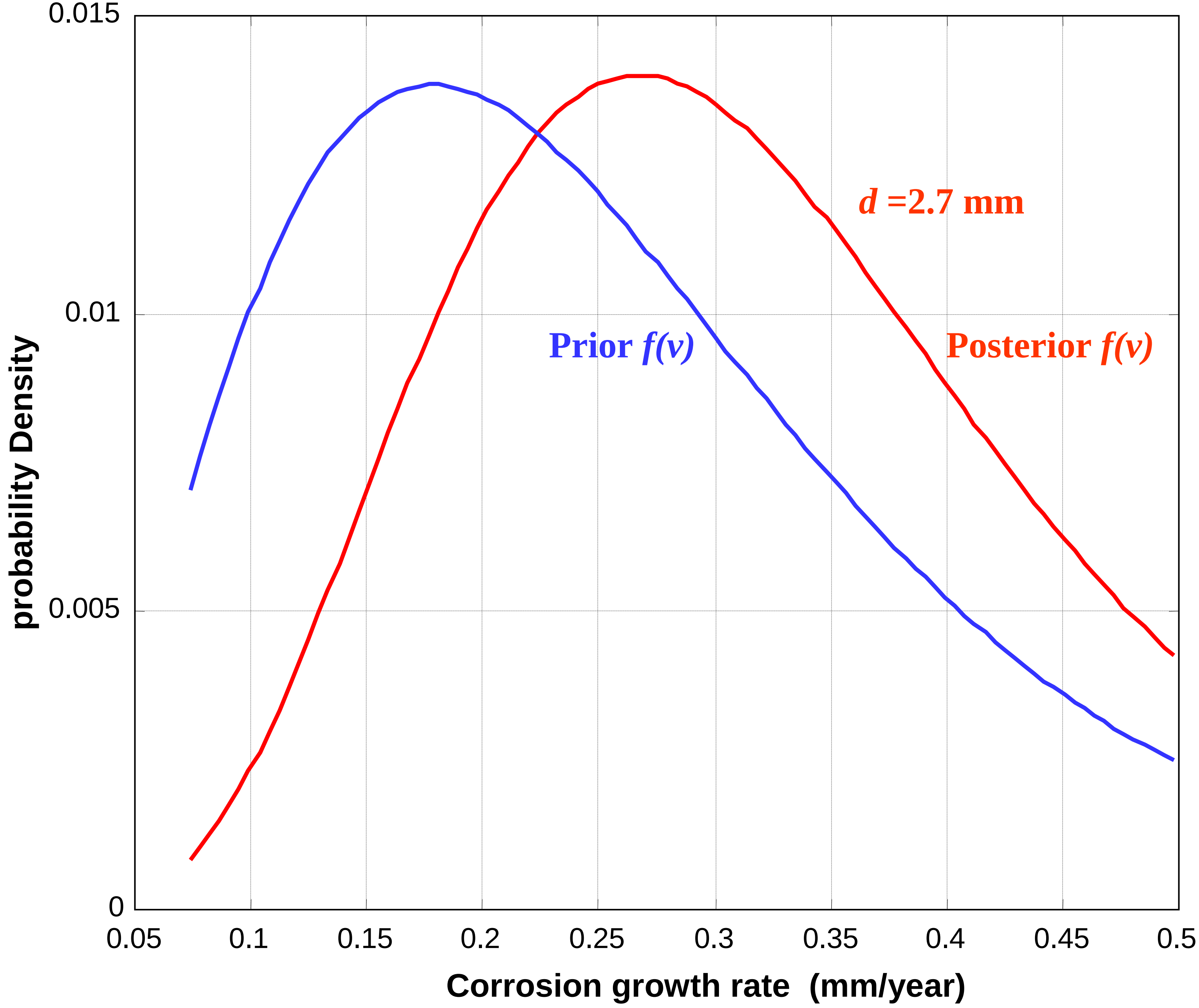
Single inspection
Two inspections on Other pipelines
Vmean
f 2 (V)
Deterministic Model
Stochastic Model
Bayesian Inference
Prior Gamma Law
Vmin
Vavr
Vmax
Posterior Law
Prior Uniform Laws
Vmin
Vavr
Vmax
f 1(V)

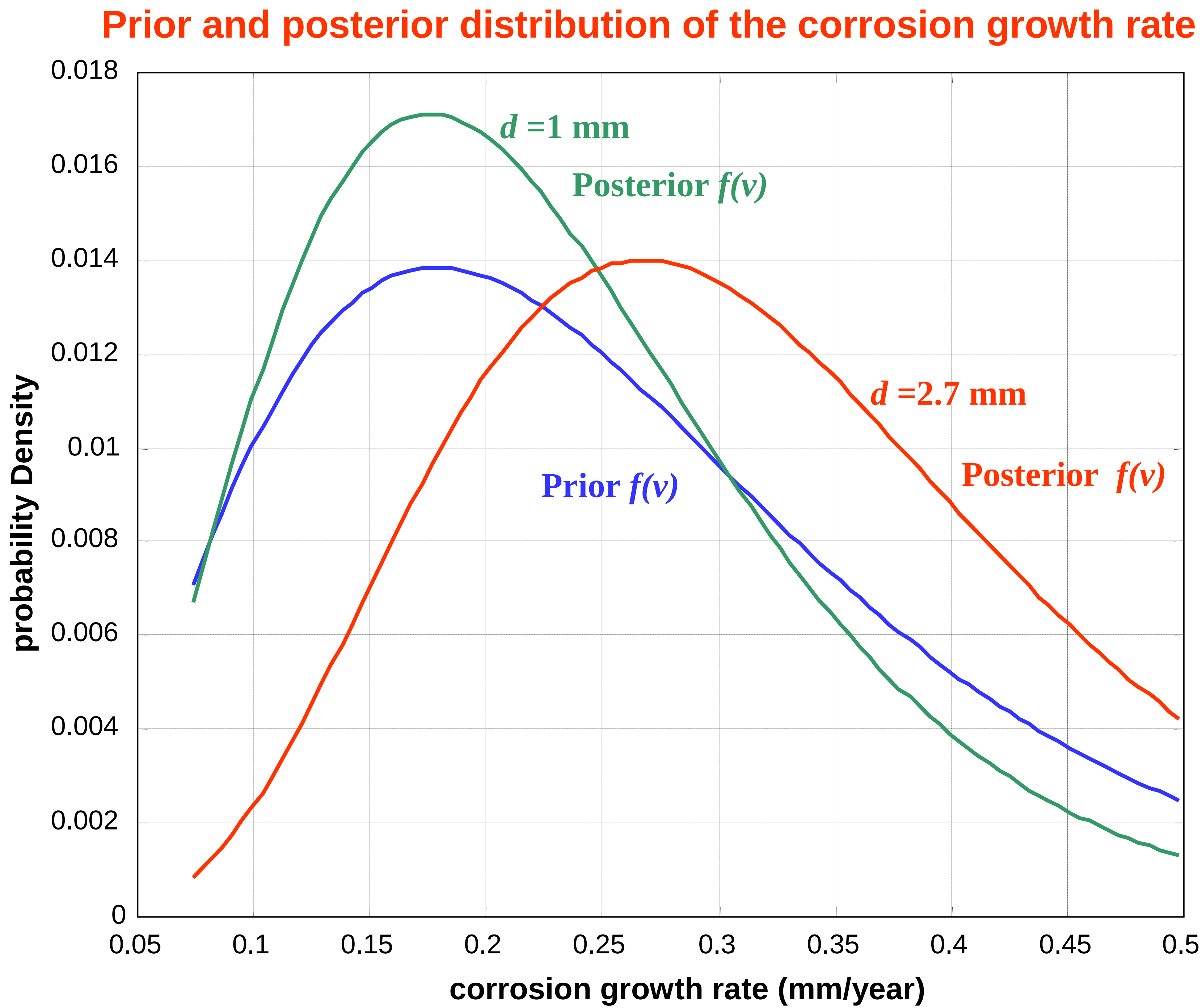
Posterior distribution of the corrosion growth rate

$$f(V)=\frac{(\theta_0+\xi_p)^{(\beta_0+d_i)}}{\Gamma(\beta_0+d_i)}\cdot V^{(\beta_0+d_i-1)}\cdot Exp(-(\theta_0+\xi_p)\cdot V)$$

At the present **time**, this type of **results** is provided by **operators** only on the basis of **multiple** inspections.

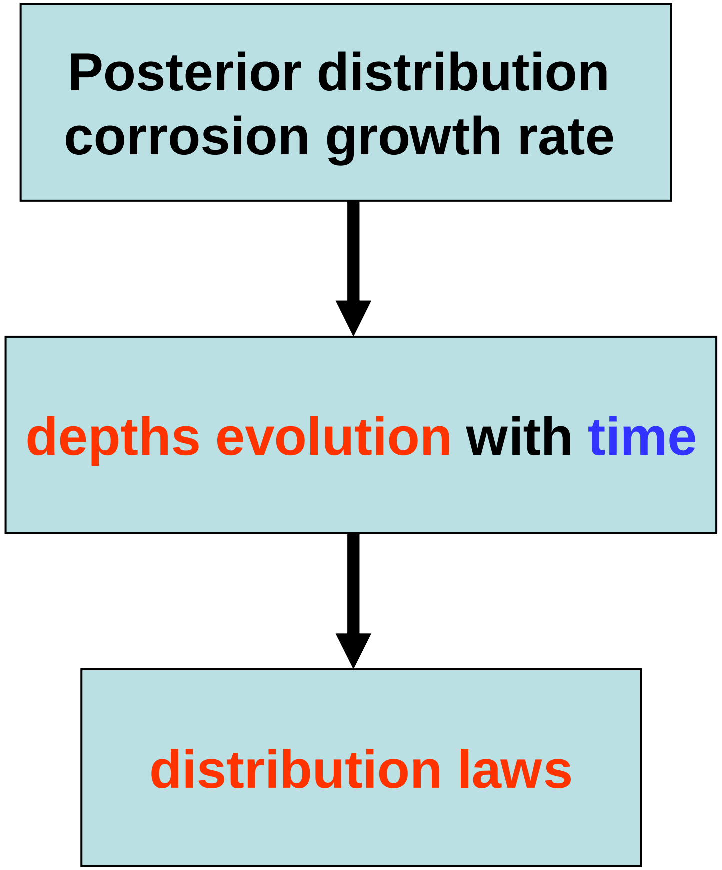
Prior and posterior distribution of the corrosion growth rate





Prior and posterior distribution of the corrosion growth rate
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
probability Density
corrosion growth rate (mm/year)
d =1 mm
Posterior f(v)
d =2.7 mm
Posterior f(v)
Prior f(v)

Determination of the depths distribution



$$f(V) = \frac{\left(\theta_0 + \xi_p\right)^{\left(\beta_0 + d_i\right)}}{\Gamma\left(\beta_0 + d_i\right)} \cdot V^{\left(\beta_0 + d_i - 1\right)} \cdot Exp\left(-\left(\theta_0 + \xi_p\right) \cdot V\right)$$

General expression

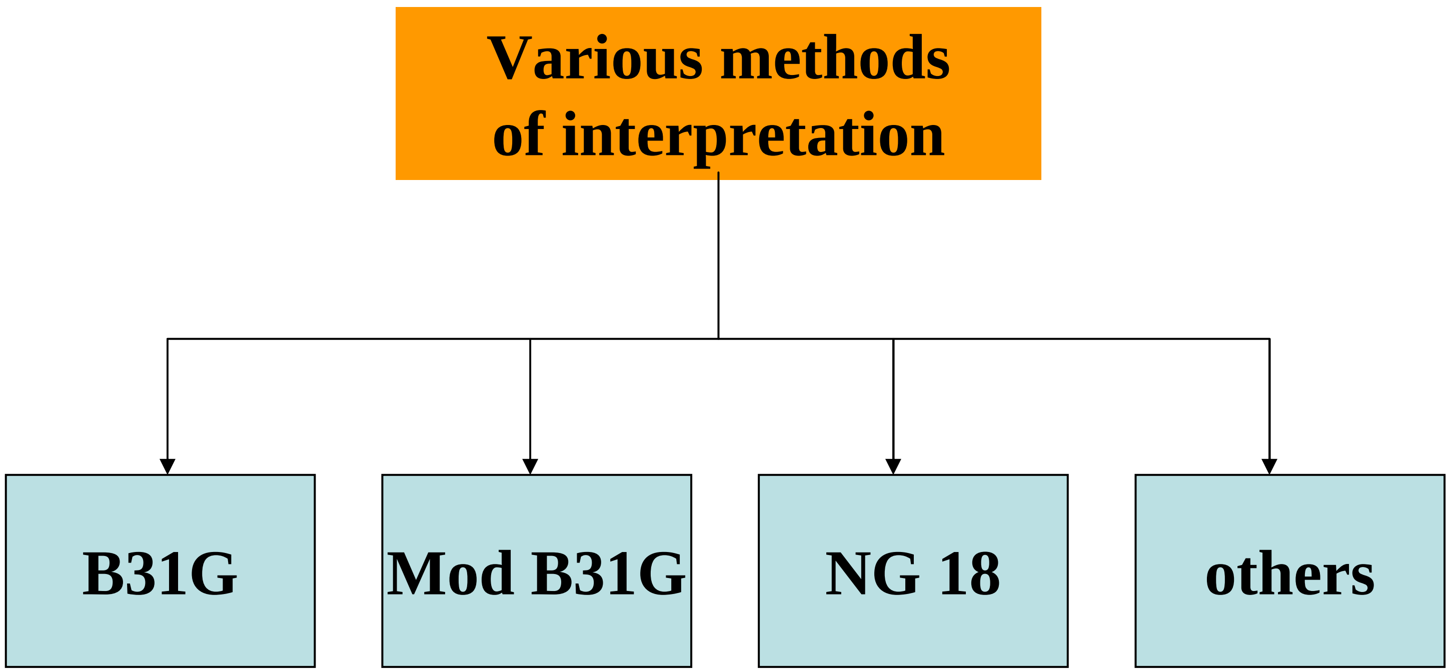
Functions of Random variable

$f(V)$	$=\dfrac{(\theta_0+\xi_p)^{(\beta_0+d_i)}}{\Gamma(\beta_0+d_i)}\cdot V^{(\beta_0+d_i-1)}\cdot Exp\left(-(\theta_0+\xi_p)\cdot V\right)$
$d=\varphi(V)$	$d=d_i+V\cdot\tau$
$V=\psi(d)$	$V=\dfrac{d-d_i}{\tau}$
$\psi'(d)$	$=\dfrac{1}{\tau}$
$\lvert\psi'(d)\rvert$	$=\dfrac{1}{\lvert\tau\rvert}$
$g(d)=f(\psi(d))\cdot\lvert\psi'(d)\rvert$	$=\dfrac{1}{\tau}\cdot\dfrac{(\theta_0+\xi_p)^{(\beta_0+d_i)}}{\Gamma(\beta_0+d_i)}\cdot\left(\dfrac{d-d_i}{\tau}\right)^{(\beta_0+d_i-1)}\cdot Exp\left(-(\theta_0+\xi_p)\cdot\left(\dfrac{d-d_i}{\tau}\right)\right)$

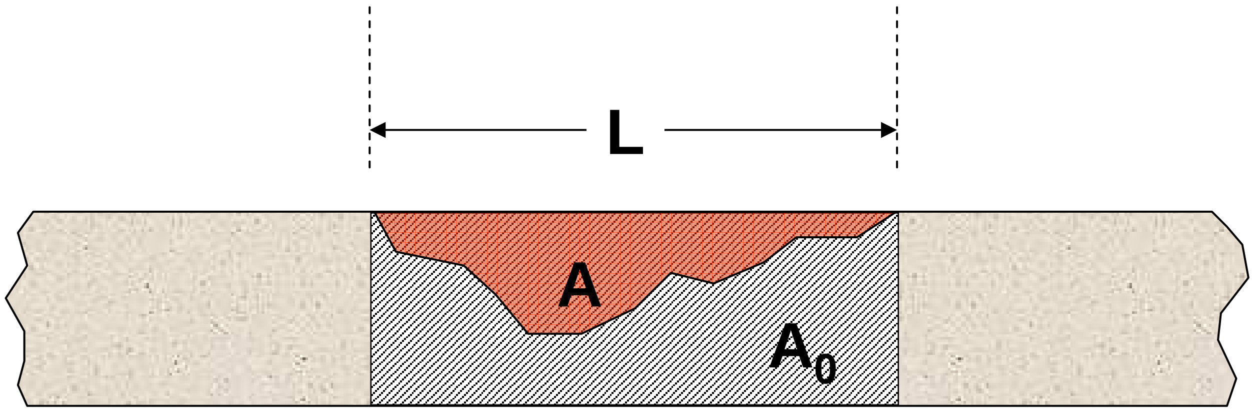
The relation expressing the law of depths distribution and their evolutions with time is given as follows:

$$g(d)=\frac{(\theta_0+\xi_p)^{(\beta_0+d_i)}}{\Gamma(\beta_0+d_i)\cdot\tau}\cdot\left(\frac{d-d_i}{\tau}\right)^{(\beta_0+d_i-1)}\cdot Exp\left(-(\theta_0+\xi_p)\cdot\left(\frac{d-d_i}{\tau}\right)\right)$$

Limit state Function (according to ASME B31 G)



Assessment of Part-Wall Defects



$$\frac{\sigma}{\bar{\sigma}} = \left[\frac{1 - \frac{A}{A_0}}{1 - \frac{A}{A_0} M^{-1}} \right]$$

Where:

σ	=	Failure stress
$\bar{\sigma}$	=	Flow stress
A	=	Area of metal loss
A_0	=	Original Area
M	=	Folias Bulging Factor f(L,D,t)

$$d_R = t\left(\frac{[\sigma]-\sigma_f}{[\sigma]-M^{-1}\sigma_f}\right)$$

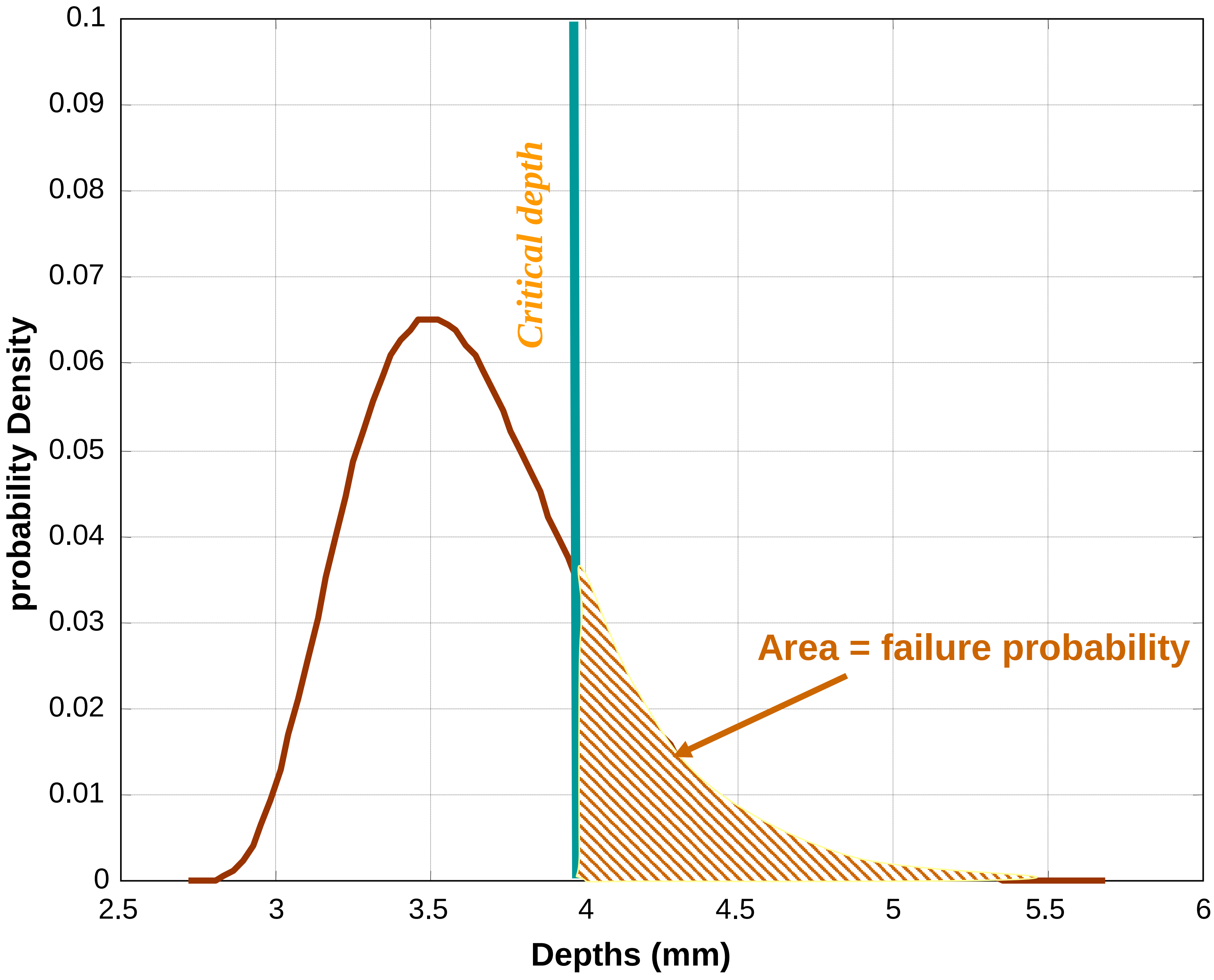
As the **evolution** of the **corrosion depth** with time is a random variable, the probability of failure is then defined by the integral :

$$P_R = \int_{d_R}^{t} f(d)dd = F(t) - F(d_R) = 1 - F(d_R)$$

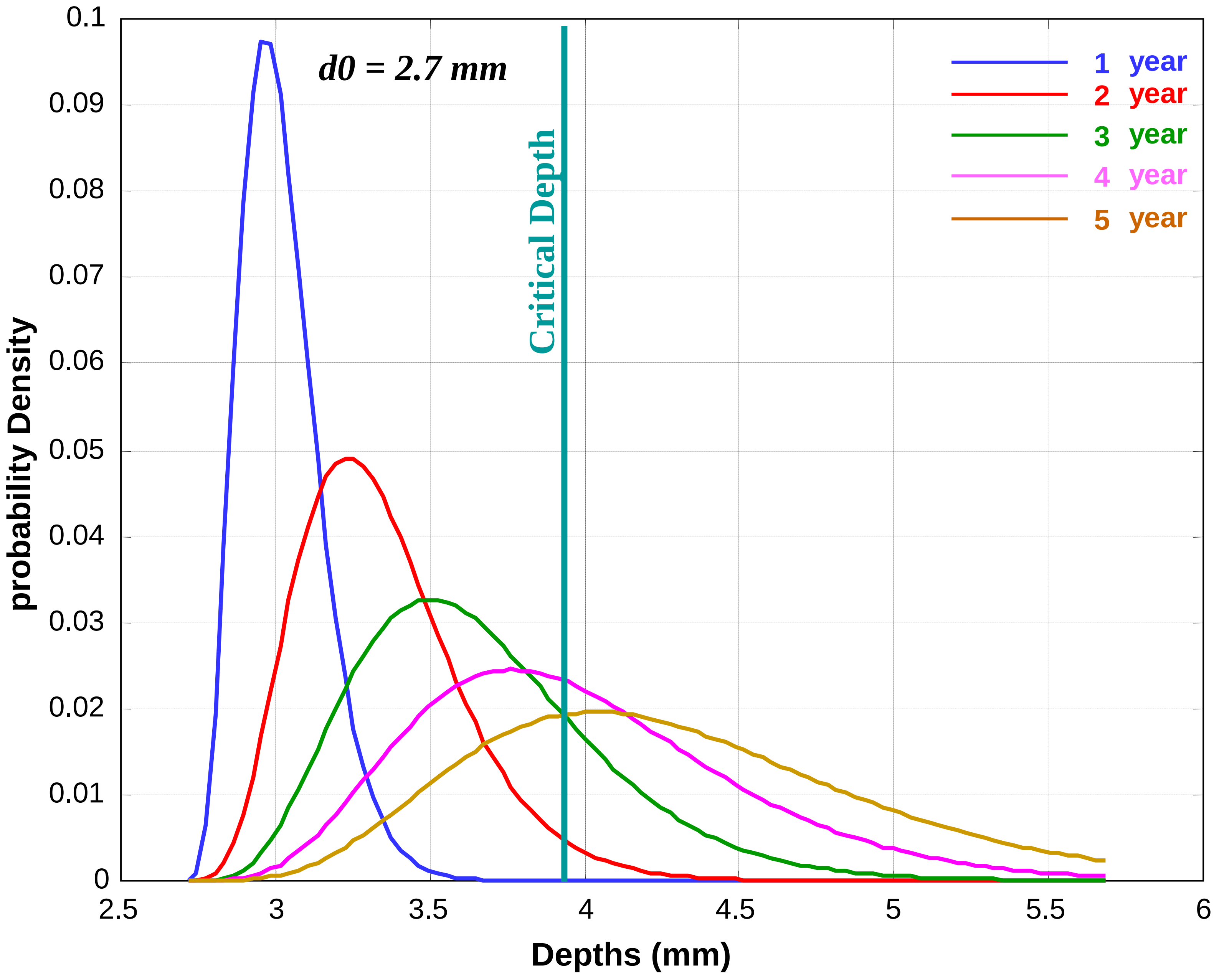
Finally the probability of pipeline rupture:

$$P_{R\_PIPE} = \sum_{i=1}^{n} P_{Ri}$$

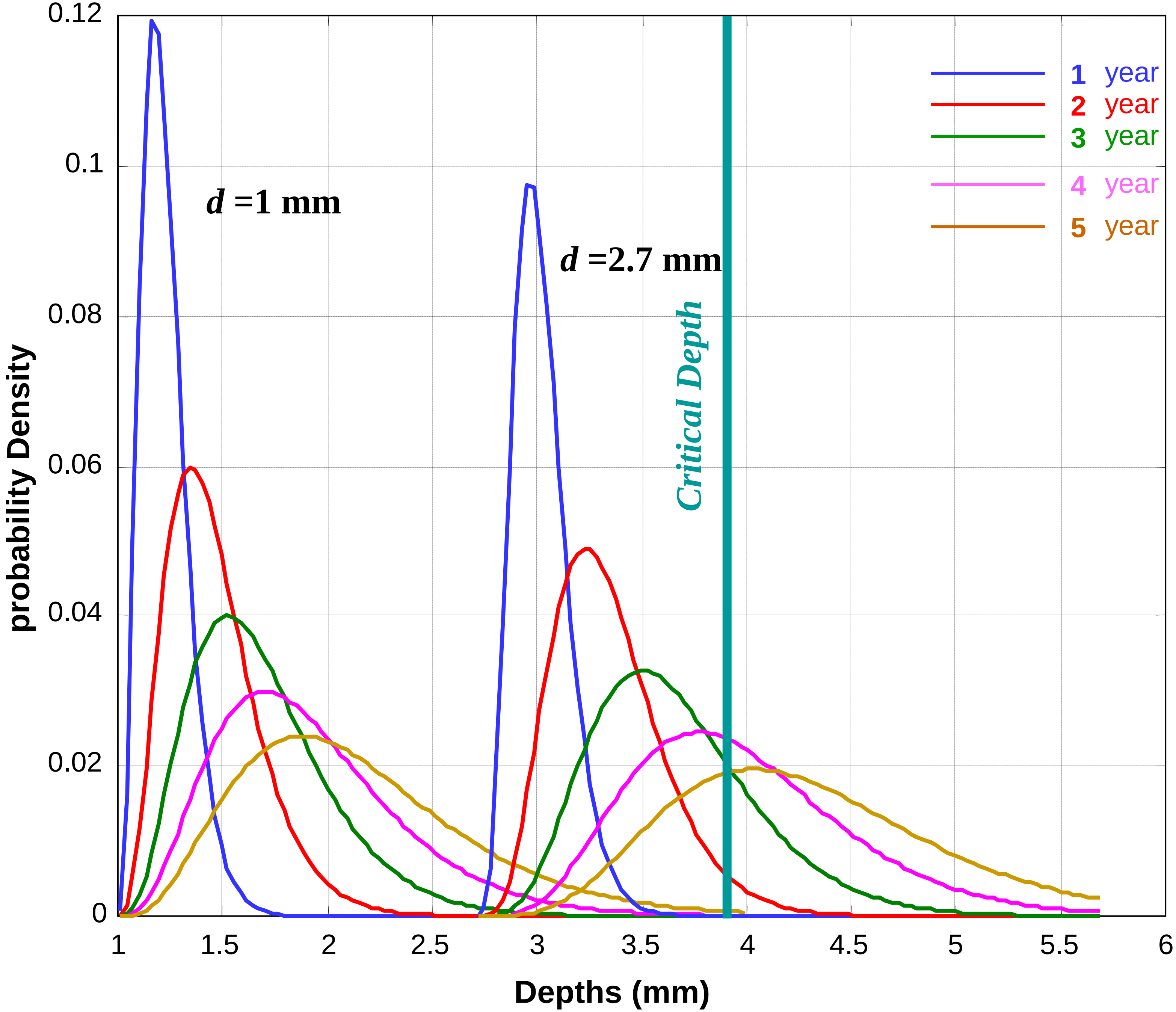
Failure probability of a corrosion point



Probable evolution of one corrosion point depth with time



Probable evolution of two corrosion points depth with time



CONCLUSION

- The corrosion of pipelines represents one of the major environmental challenges in the world today.

- Without a best practices corrosion prevention strategy, corrosion will continue and the cost of repairing a deterioration pipeline will escalate.

- Significant savings are possible by optimizing the inspection and corrosion prevention strategies.

- In order to achieve such optimization, improved prediction models for corrosion need to be developed.

- In-line inspection (ILI) operations present the **disadvantage** of being excessively expensive, from where the importance to grant to rigorous planning of these operations.

- Pipelines currently in exploitation all over the world have not undergone more than two inspections, most often having been inspected only one time during their exploitation. Which makes the accumulated information very reduced.

- The forecast of the corrosion evolution with time for the pipelines having undergone a single inspection becomes very delicate.

- In this communication we presented an approach of **resolution** of this problem of corrosion **growth rate** assessment while being based on a **probabilistic** model which is the **Bayesian inference**.

❖ This approach can assist pipeline operators in defining the **future integrity management strategy** and in maintaining the integrity of their gas pipelines while optimizing In Line inspection intervals, resulting in cost-effective pipeline integrity.