

Y. ORMIERES

Fire risk analysis method for nuclear installations

Fire risk analysis method for nuclear installations

- A position on the management of fire safety analysis in nuclear installations by specifying:
 - the fire risk analysis process
 - the demonstrative elements expected in terms of nuclear safety

Bases of reflexion

- Take into account all fire effects

Effects of the fire often restricted at the temperature of gases

- Smoke

- Dysfunctions of equipments
- Toxicity, visibility...



- Thermal radiant flux

- Variations of pressure related to fire (\sim daPa)...



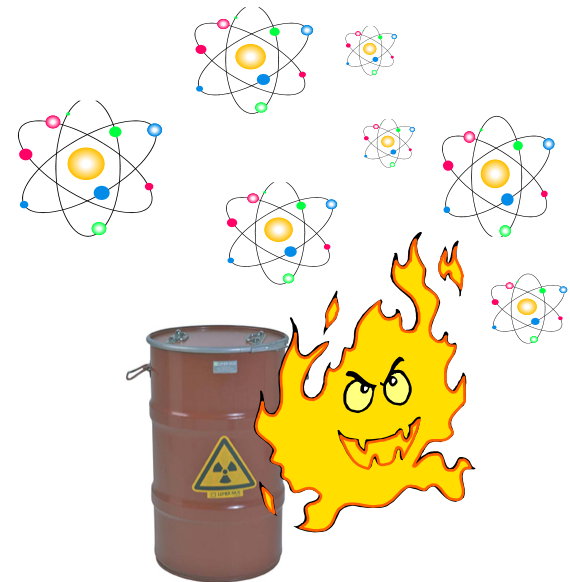
- Evolutions of the state of the art in the field of fire analysis

- Performance-based approach

Process for fire safety analysis

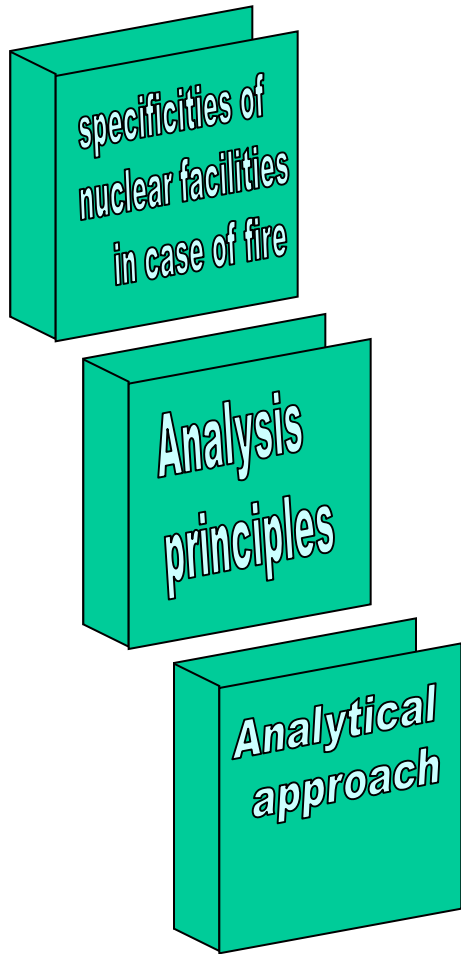
Fire and Nuclear safety considerations

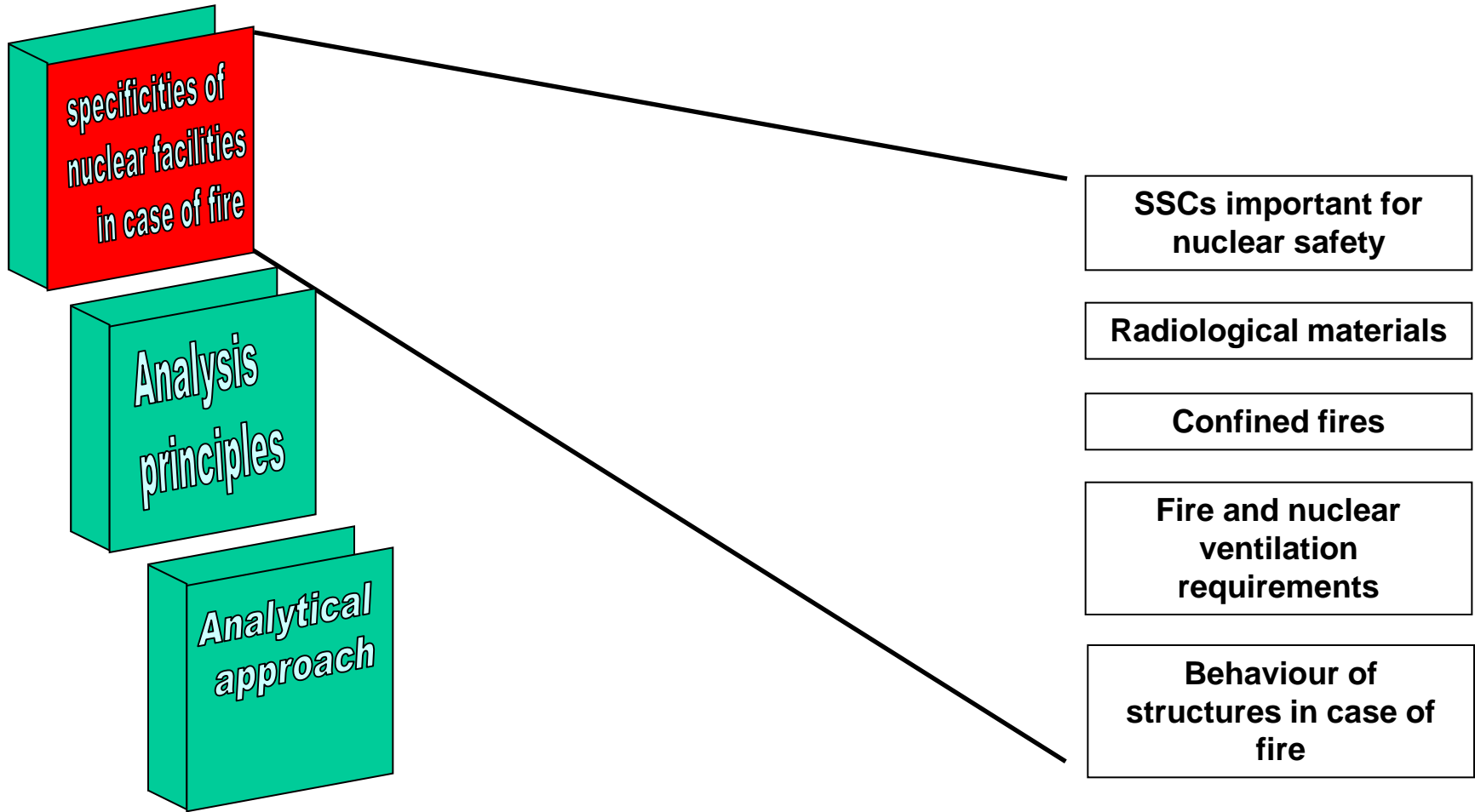
- Fire can damage structures, systems and components (SSCs) important for safety
- Fire can spread radioactive materials



Fire safety analysis of a nuclear facility

- The fire analysis aims to achieve the highest possible level of safety
 1. Take into account safety goals specific to the studied facility (to maintain functions important for safety, to protect SSCs...)
 2. Identify fire hazards
 3. Justify the adequacy of fire protection measures in case of fire
 4. Estimate consequences on facility safety in case of fire for degraded situations





Specificities of nuclear facilities

- SSCs important for nuclear safety
 - Fire can damage nuclear risk protection measures (criticality, irradiation, residual heat...)
 - Fire smoke is toxic and could affect staff with safety actions to achieve

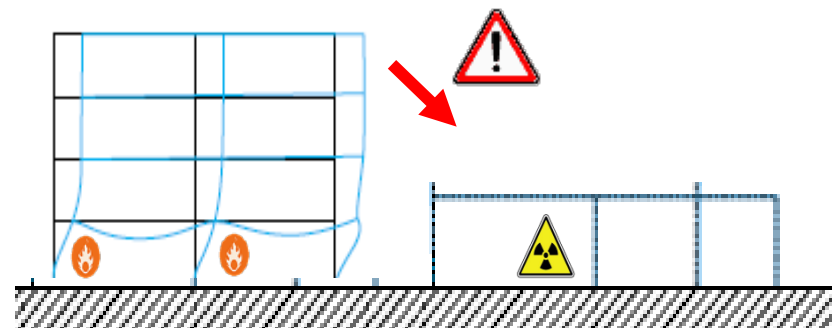
- Radiological materials
 - Dispersion hazards
 - Fire could cause an airborne release of radiological materials
 - Liquid extinguishing agents could be contaminated
 - Criticality

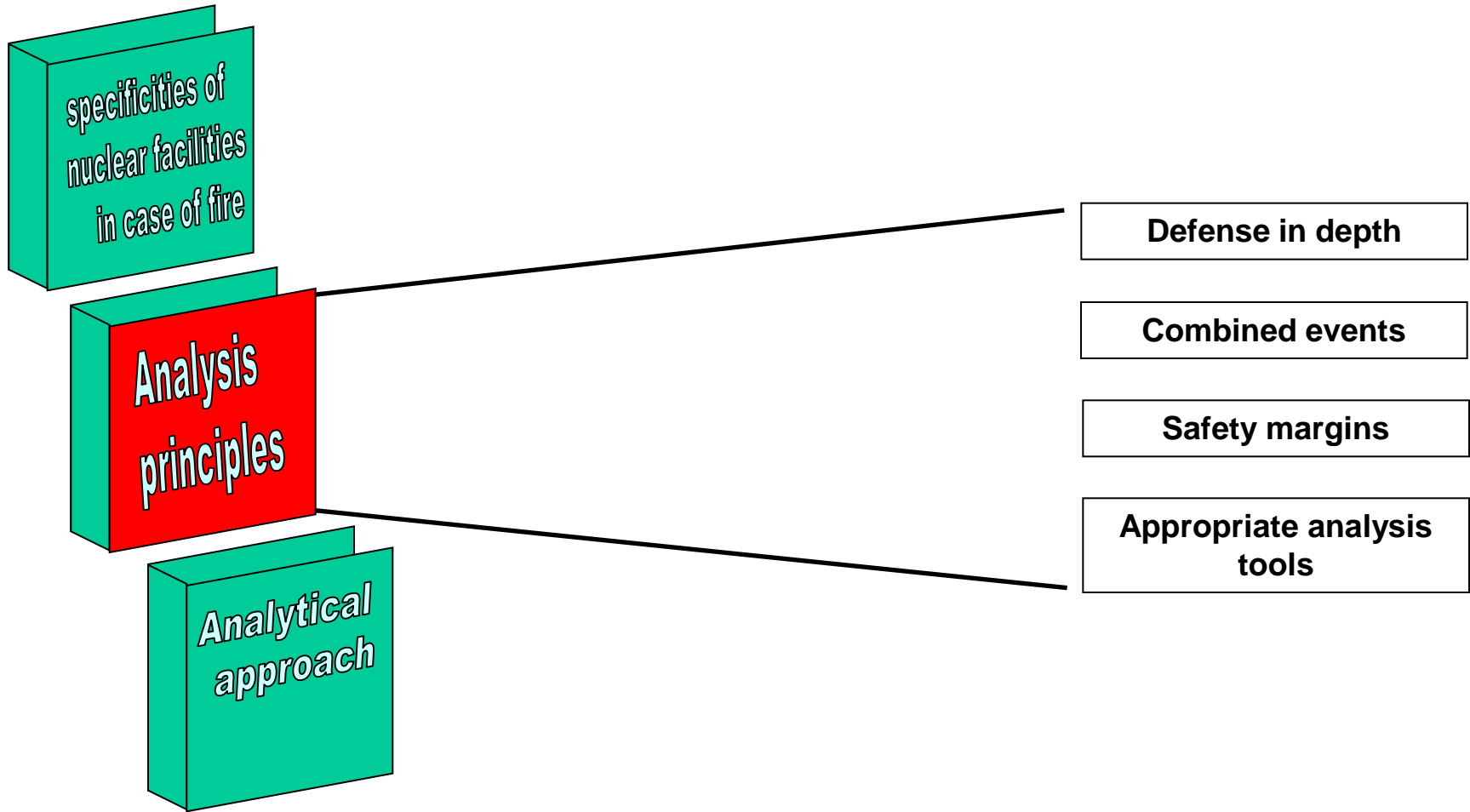
Specificities of nuclear facilities

- Confined fires
 - The prevention of risks involving the uncontrolled dispersion of radioactive materials in the atmosphere is based on containment systems
 - These systems can amplify the effects of fire
 - The production of unburned gas generated by under-ventilated fire, due to containment, is a significant risk of smoke explosion and fire spread by ignition of unburned gas (in particular by ventilation system)
- Nuclear ventilation in case of fire
 - The pressure and temperature, increase together with the smoke produced by fire, can disorganize air circulation in the facility and destroy the ventilation filters. Release to the environment could then ensue.

Specificities of nuclear facilities

- Behaviour of structures in case of fire
 - Fire stability of structures housing or supporting safety targets must be guaranteed for the duration required to implement and maintain the facility in a safety state (this duration is generally “infinite”)
 - This stability means for a fire occurring within or outside safety buildings, considering the consequences of possible interactions due to a fire developing in adjoining buildings.





Principles to include in a safety demonstration

- Defense in depth (1/2)
 - Defence in depth is implemented primarily through the combination of a number of consecutive and independent levels of protection:
 - prevention of abnormal situations
 - preventing their degradation
 - limitation of their consequences
 - Fire defence in depth levels:
 - Preventing fires from starting
 - Detecting and extinguishing quickly those fires which do start, thus limiting the damage;
 - Preventing the spread of those fires which have not been extinguished, thus minimizing their effects on essential plant functions

Principles to include in a safety demonstration

- Defense in depth (2/2)
 - It is a deterministic method, since a certain number of incidents and accidents are postulated
 - When properly implemented, defence in depth ensures that no single technical, human or organizational failure could lead to harmful effects, and that the combinations of failures that could give rise to significant harmful effects are of very low probability [IAEA SF-1]

Principles to include in a safety demonstration

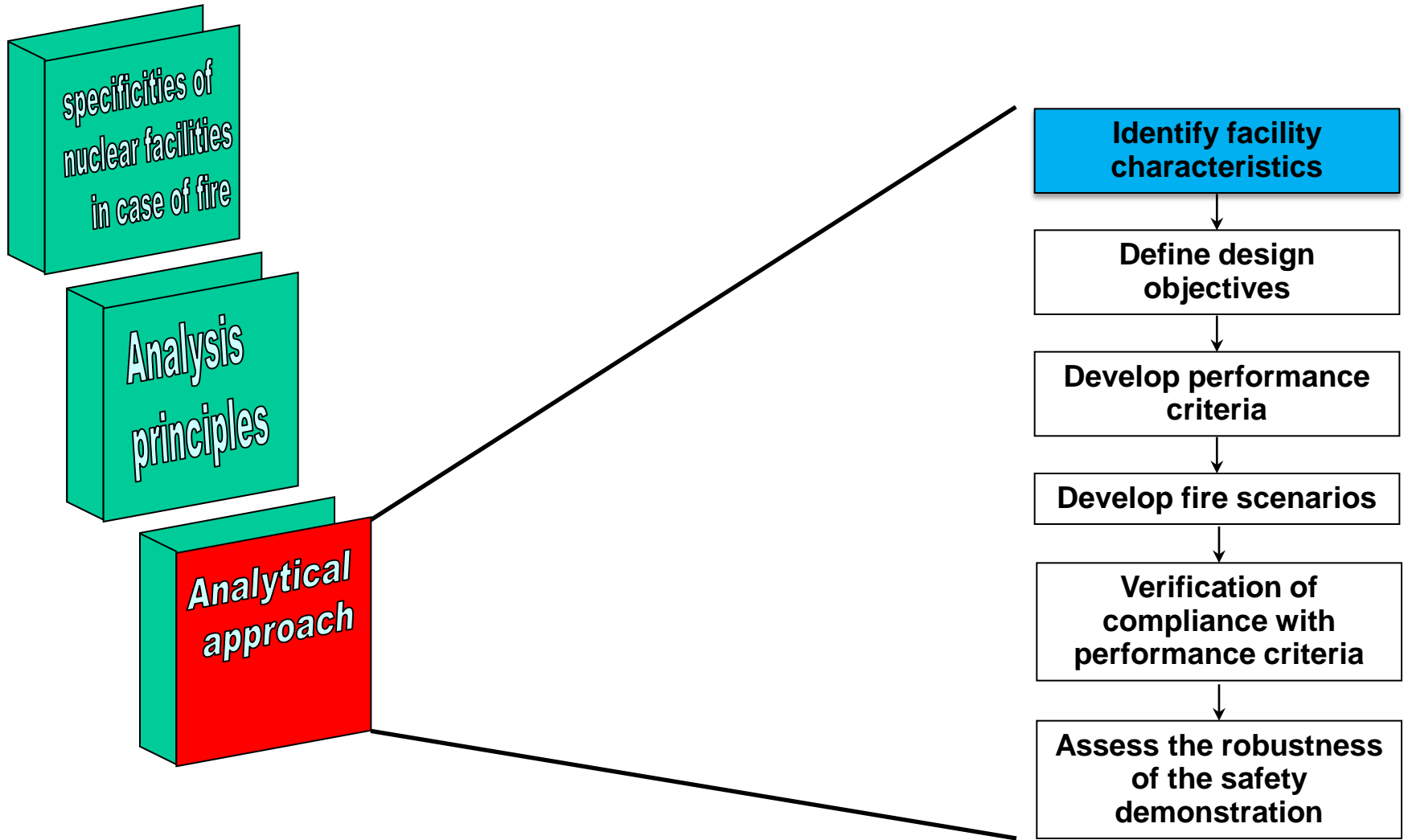
- Combined events

- Occurrence of events that affect an installation in the same time interval. If there are no links between these events, they are considered as independent :
 - Fire and dependent events
 - Earthquake and fire,
 - Explosion and fire...
 - Fire and INdependent events is postulated
 - in conjunction with each event with a high frequency rate that is likely to affect fire protection measures:
 - winter conditions (freeze, snow...)
 - Loss of offsite power...
 - after an event downgrading the long term safety of the installation without compensatory provisions

Other principles

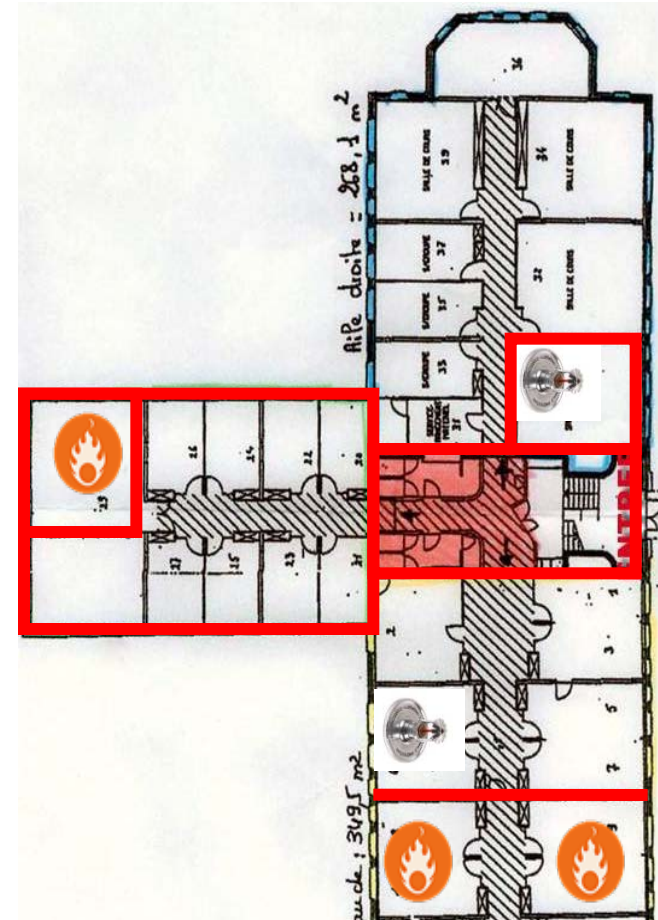
- Appropriate fire model depend on:
 - Studied fire scenario
 - Available input parameters
 - Expected outcomes

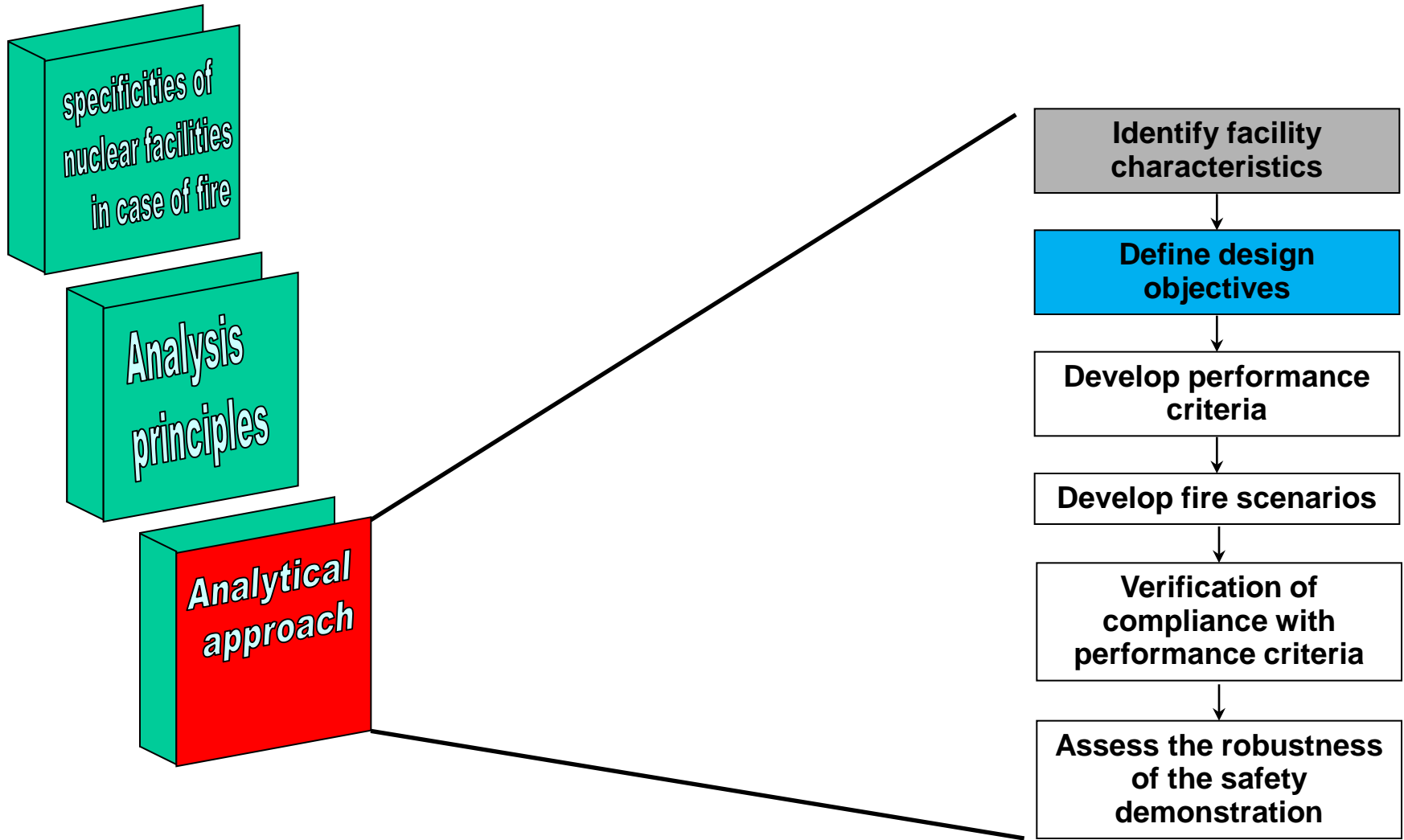
- Take into account margins and uncertainties on
 - Input data or parameters
 - Outcomes




Identify facility characteristics

- Basic characteristics
 - Type of construction
 - Number of floors
 - Processes...
- Identify fire loads
 - Electrical rooms
 - Flammable liquids
 - Transient fire loads...
- Fire protections measures
 - Fire detection systems
 - Fire compartments/walls
 - Sprinklers...

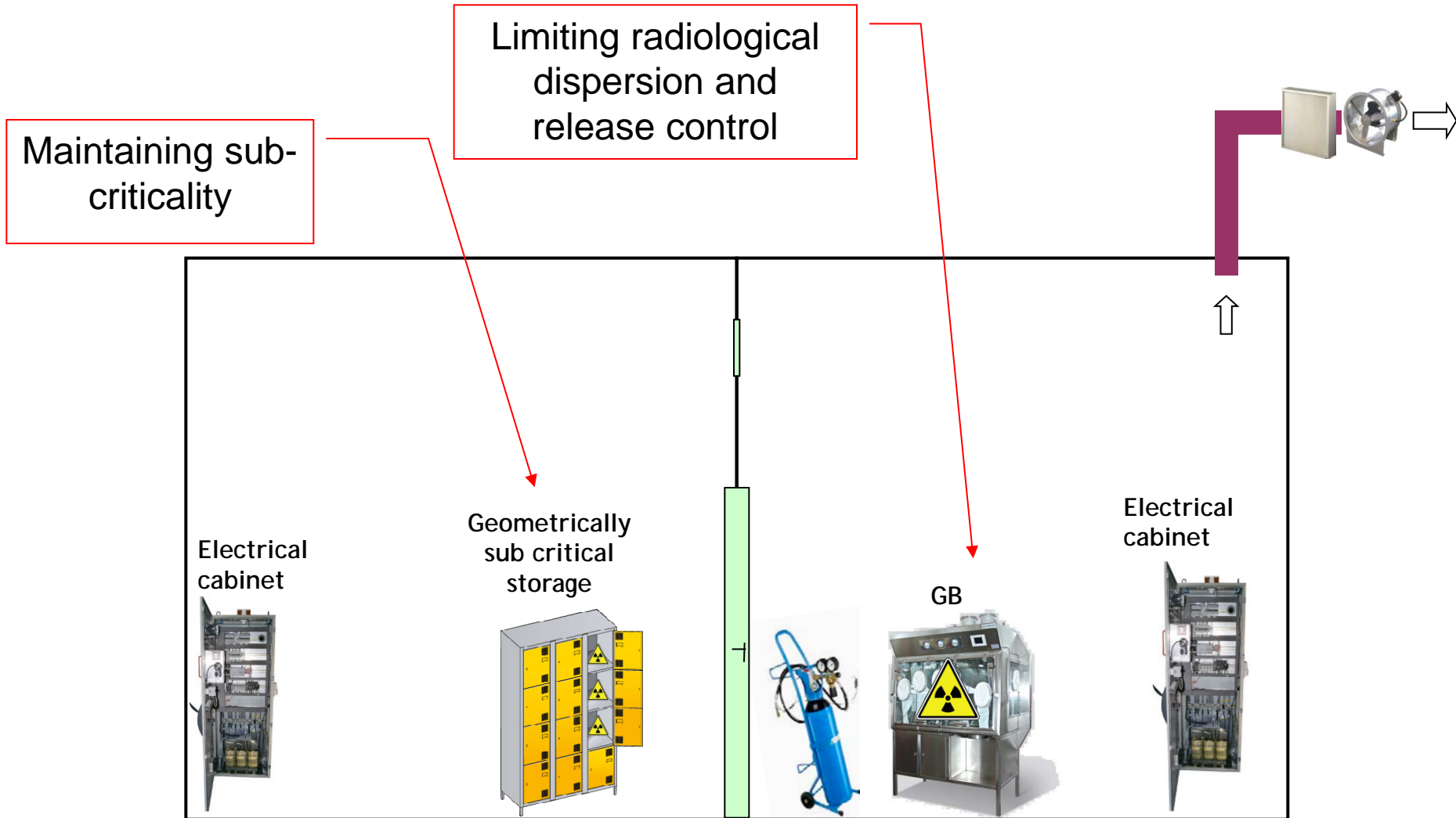




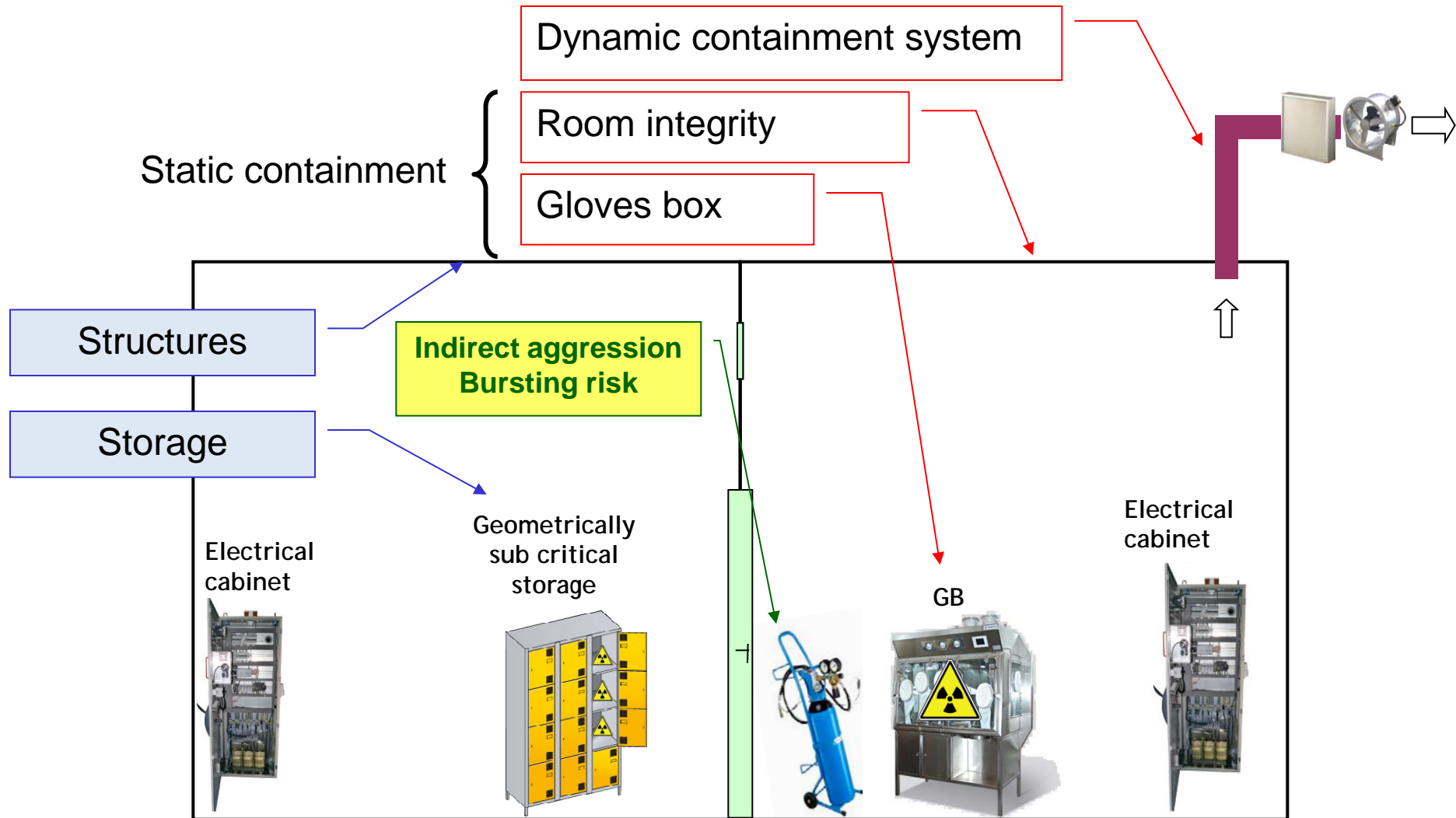
Define safety targets in case of fire

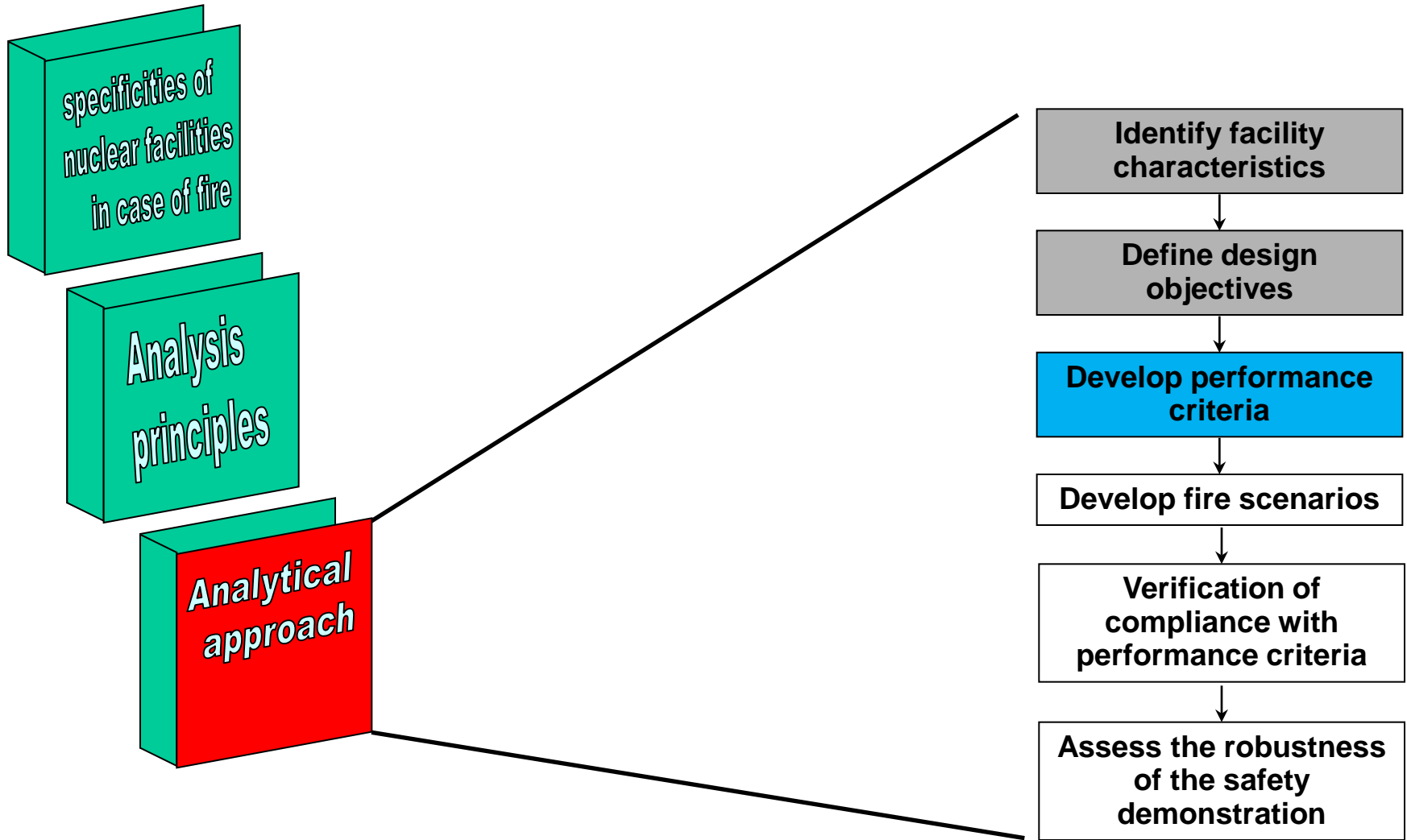
- Identify objectives
 - Nuclear safety
 - Radiation release
 - Life safety
 - Interruption
- Determine « targets »  to be protected from the fire to achieve these objectives:
 - Radiological materials
 - nature and physical status (gas, liquid, solid)
 - quantity
 - Structures, systems and components important for safety (SSCs)
 - identification of equipment taking part in safety functions
 - redundancy identification
 - Personnel...

Safety objectives



Targets to protect against fire to achieve safety objectives





Performance criteria

- To adapt fire protection measures to the vulnerability of the safety targets



Vulnerability

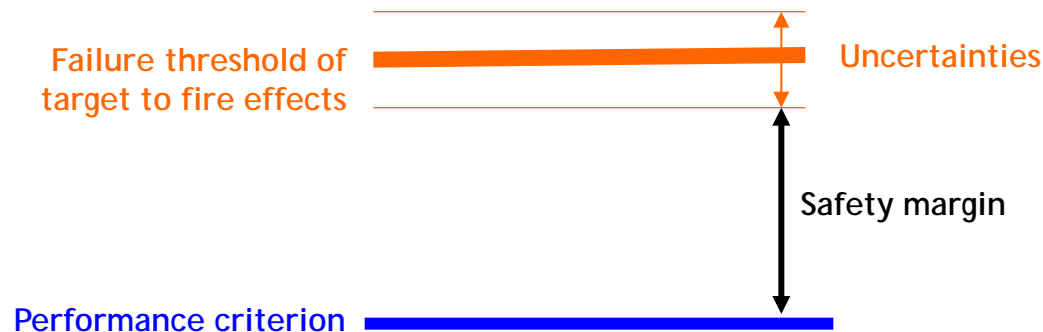


Performance criteria

- These criteria will be used to evaluate the designs proposed by the operator.
- Definition of performance criteria is based on the vulnerability of targets to the effects of fire.

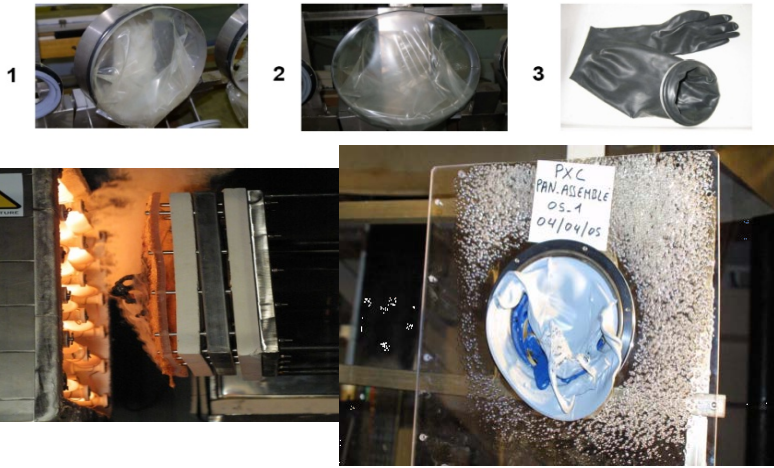
For example, performance criteria might include values for thermal radiation exposure (kW/m^2) or air temperature.

- These criteria are determined with margins.



Result of real tests

- Glove box components



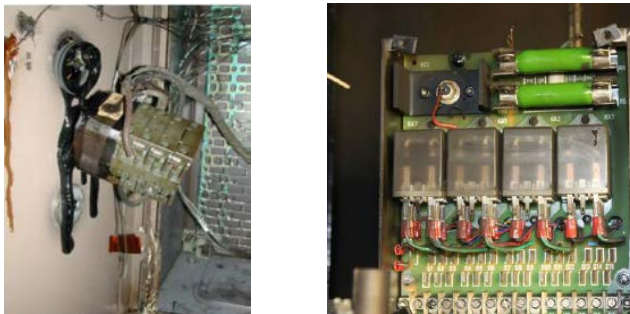
- HEPA filters



- Drums

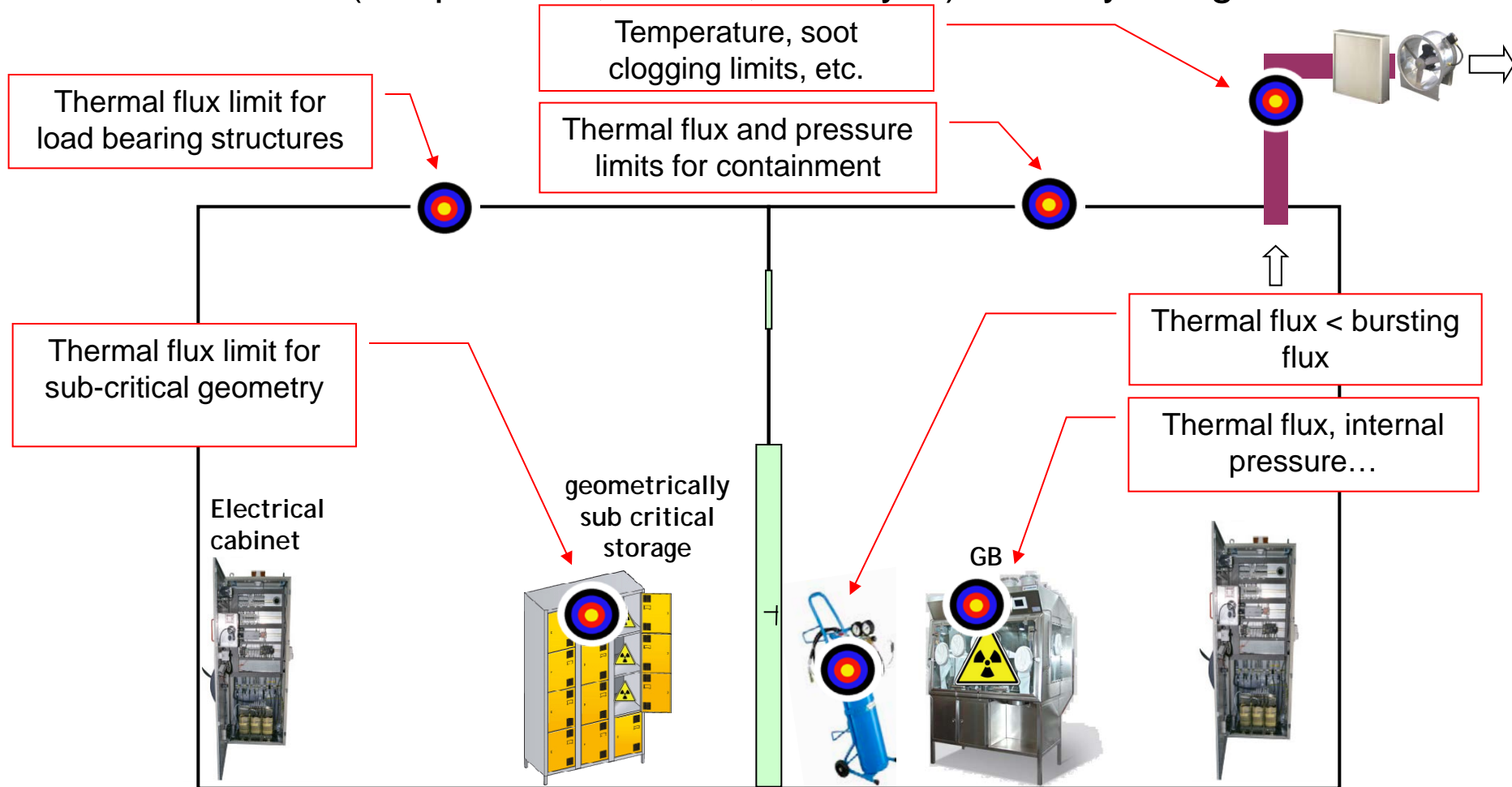


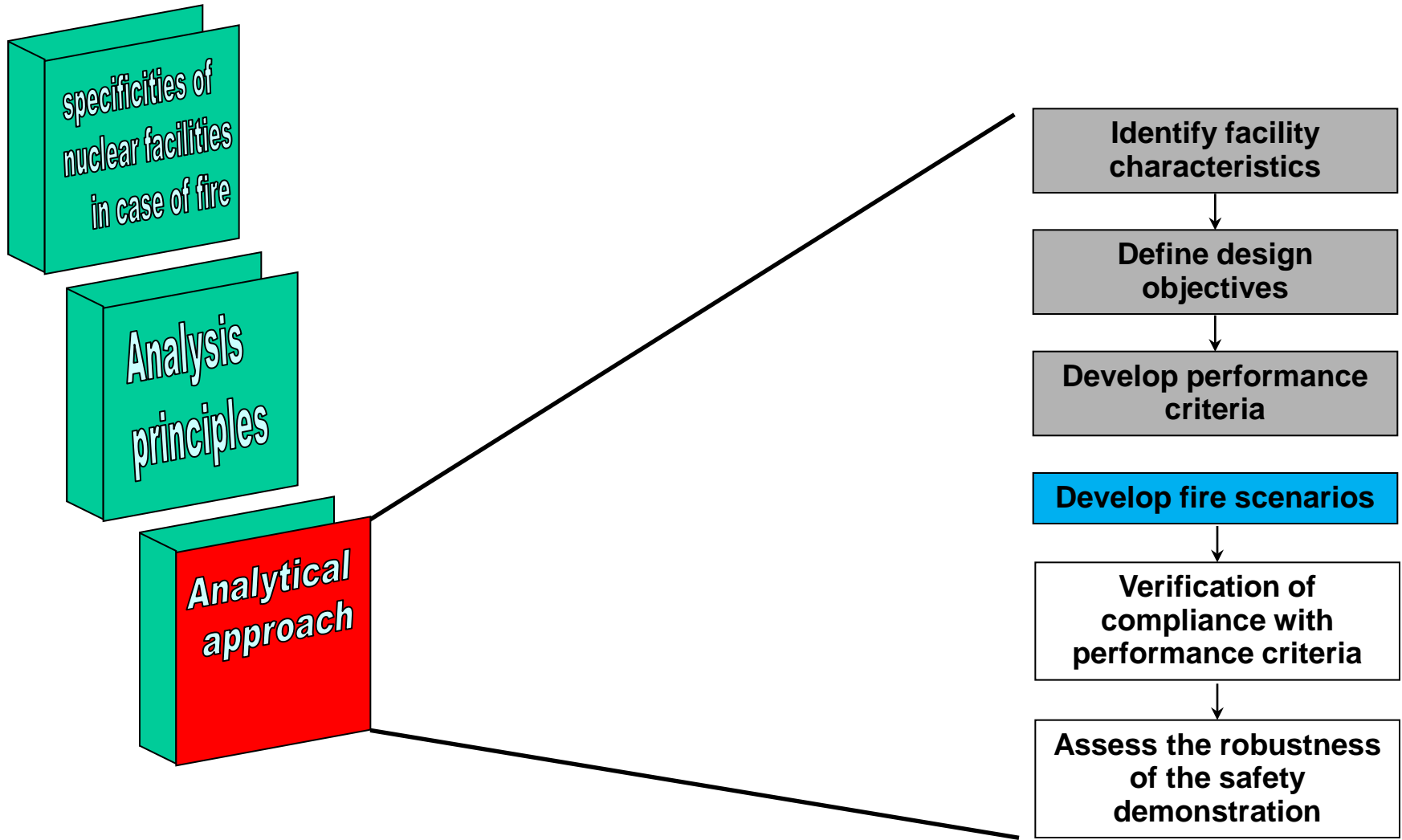
- Electrical equipments



Performance criteria

- Performance criteria depend on the sensitivity of targets to fire (temperature, smoke, toxicity...) + safety margins.





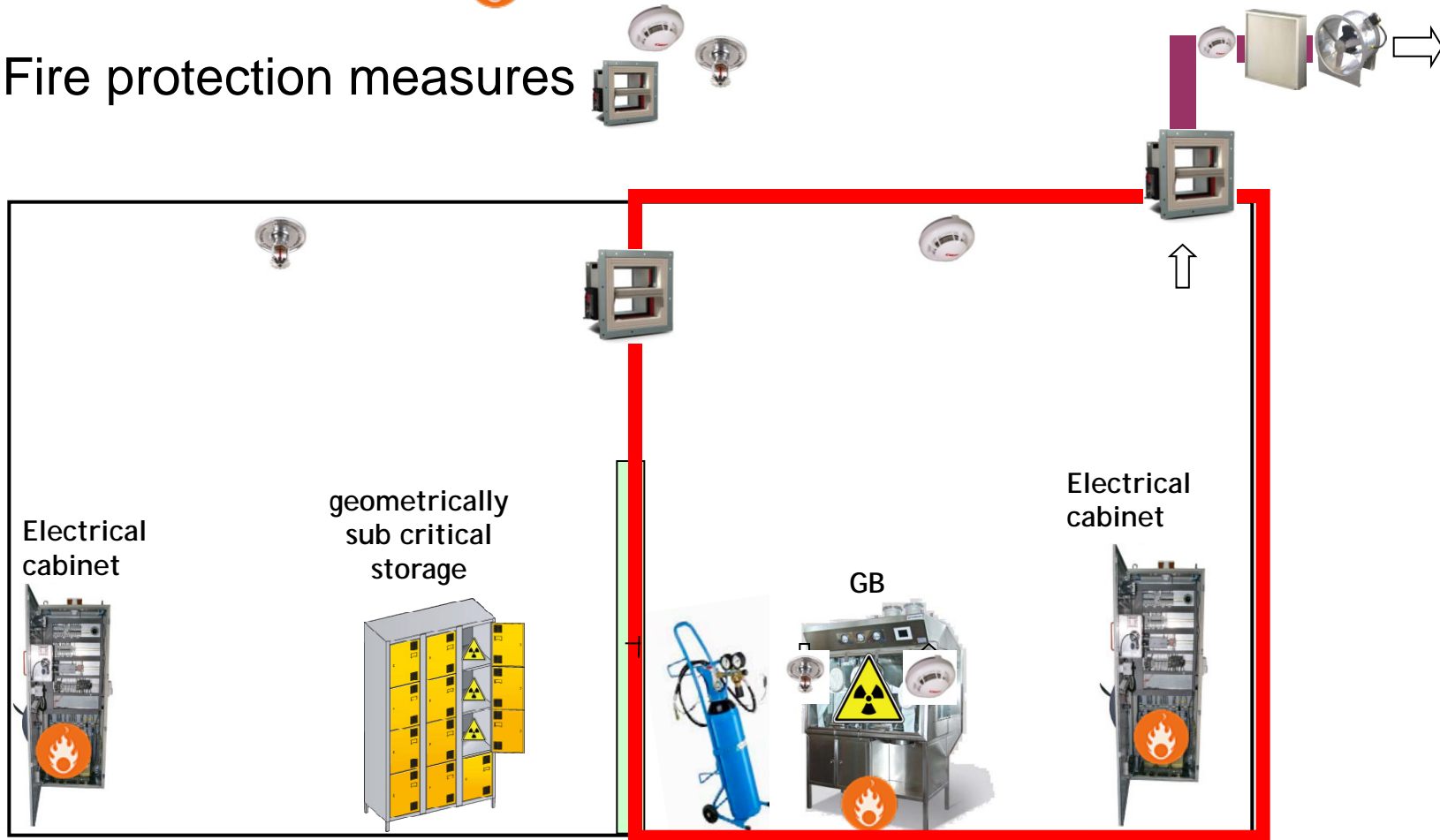
Identification of possible fire scenarios

- Ignition is postulated
 - A fire is by definition an accidental event that occurs only in abnormal operating conditions. It makes no sense to say that nothing can burn because it refers only to normal operation.
 - The feedback shows that the risk of a fire is significant
- Consider all operating conditions of the facility
 - Normal operating conditions
 - Reduced power operation
 - Scheduled maintenance or shutdown...
- Take into account combined events with fire

Fire Scenarios

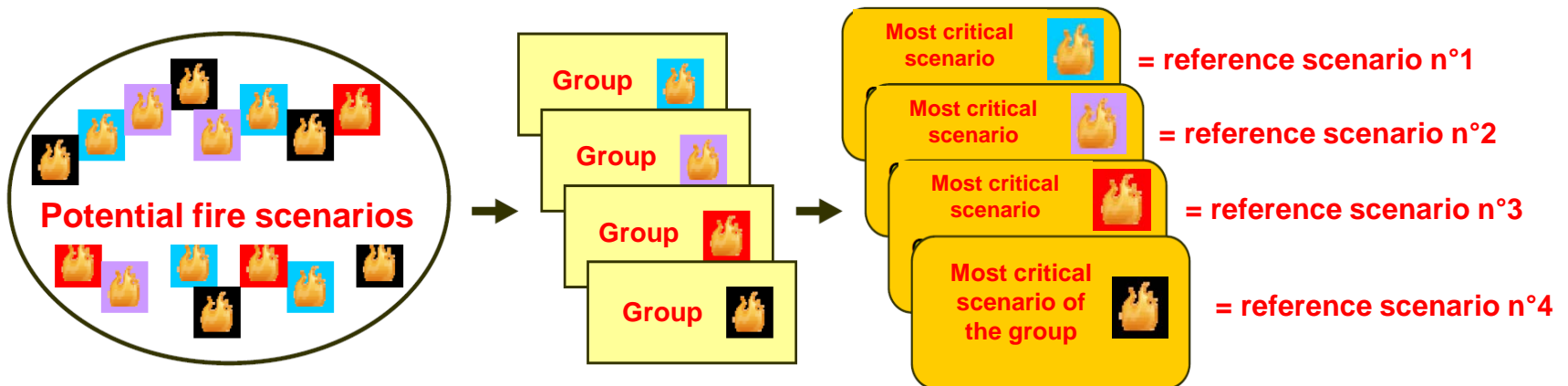
- Hazard fire sources 

- Fire protection measures



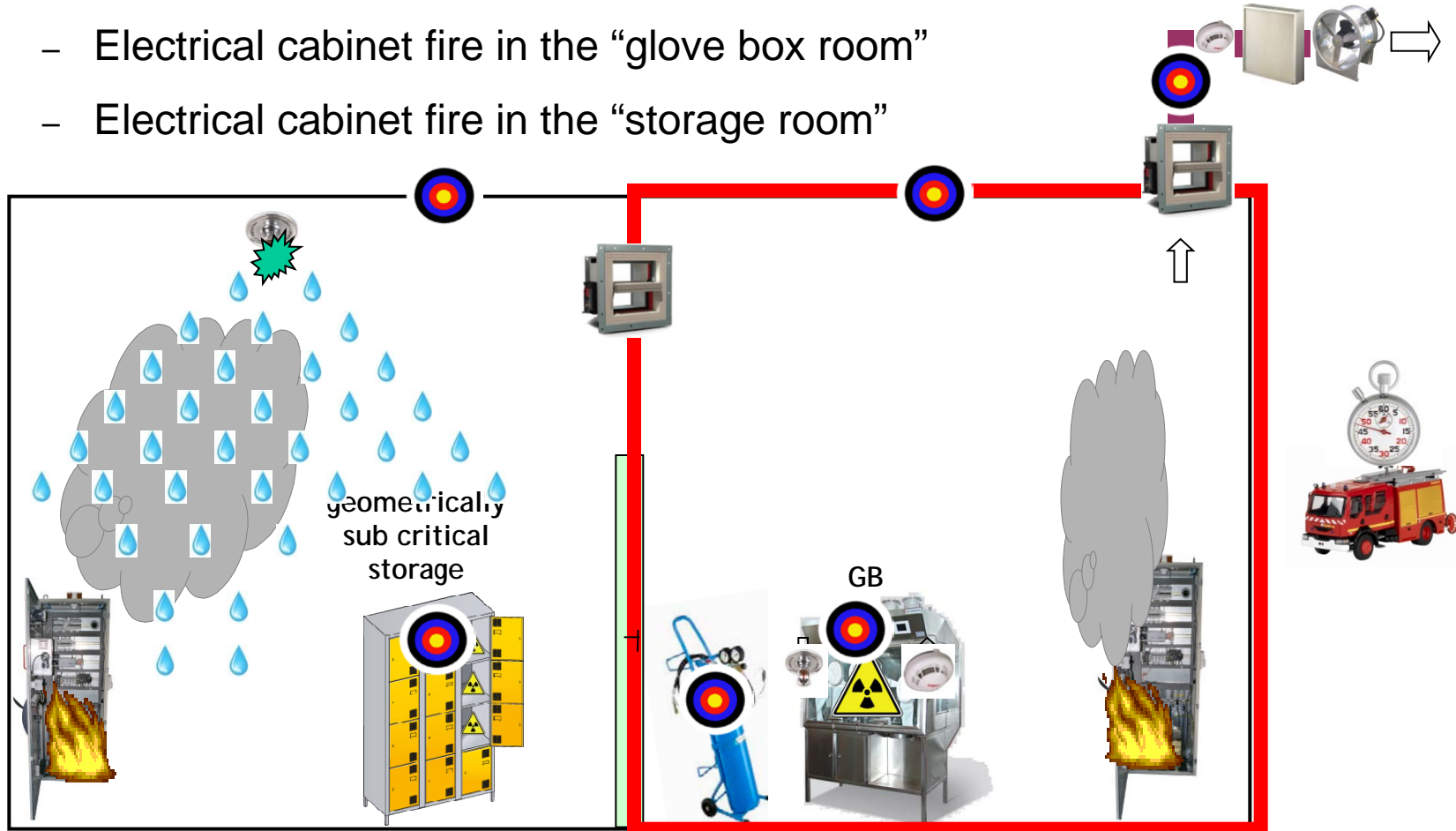
Define “reference fire scenarios”

- “Reference fire scenarios”, a subset of the possible fire scenarios
 - It is usually necessary to reduce the possible fire scenarios to a manageable number of credible “reference fire scenarios”



Reference fire scenarios

- these scenarios were selected because they are representative of all scenarios identified in terms of attacks on targets :
 - Electrical cabinet fire in the “glove box room”
 - Electrical cabinet fire in the “storage room”



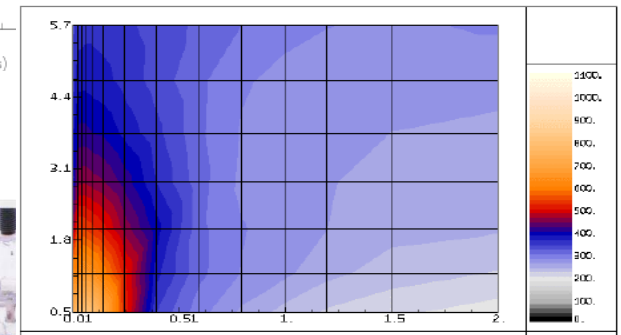
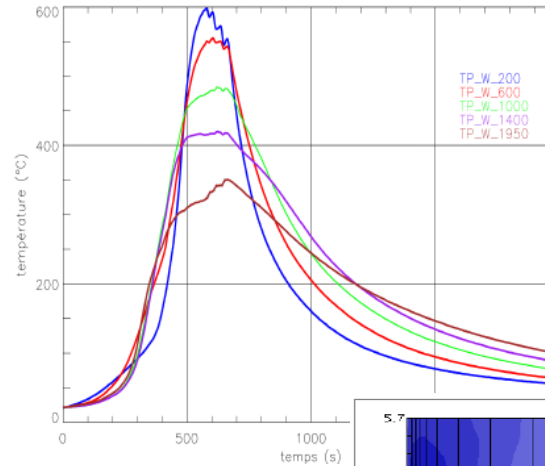
Estimate reference fire scenario effects

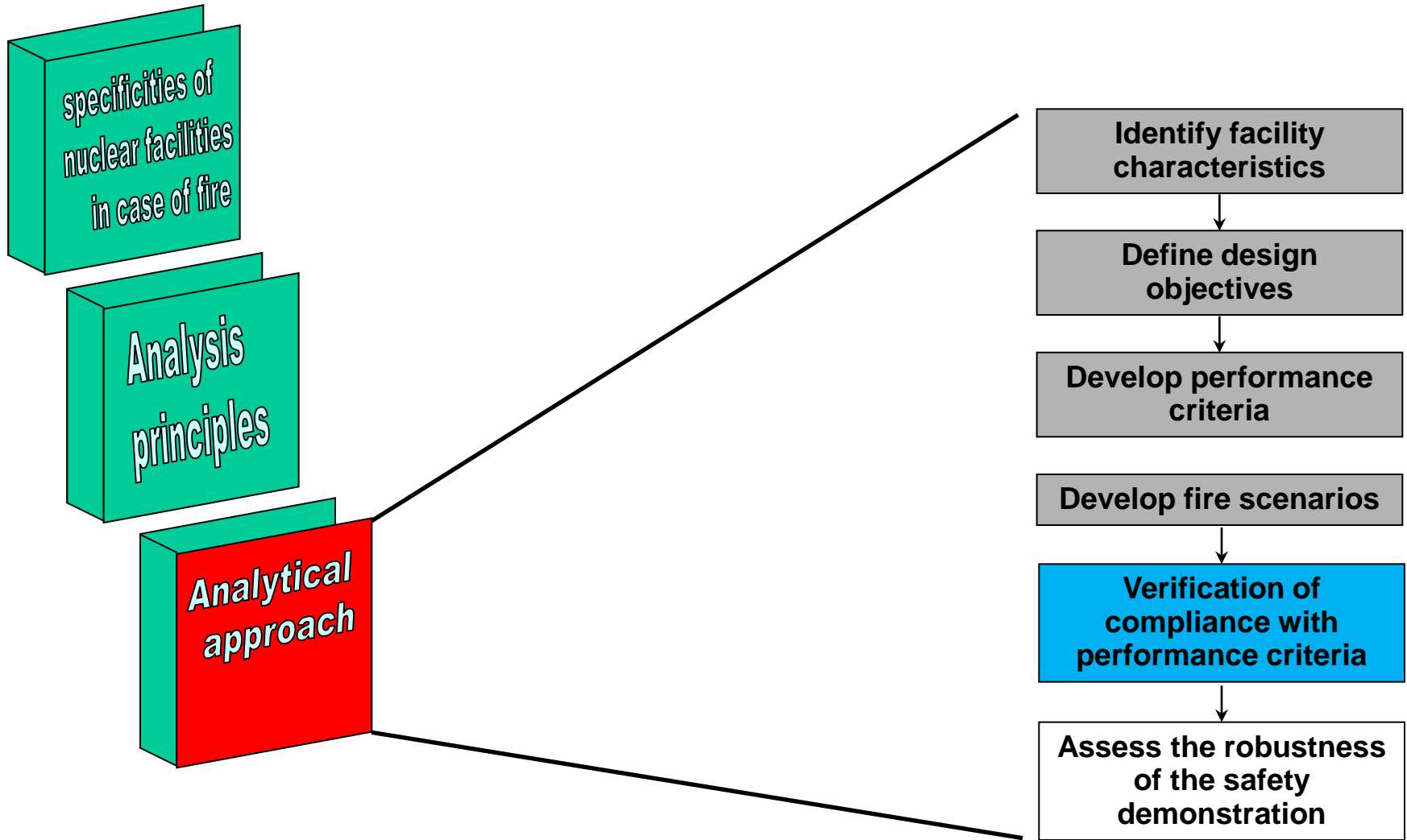
Result of real fire tests



Estimate reference fire scenario effects

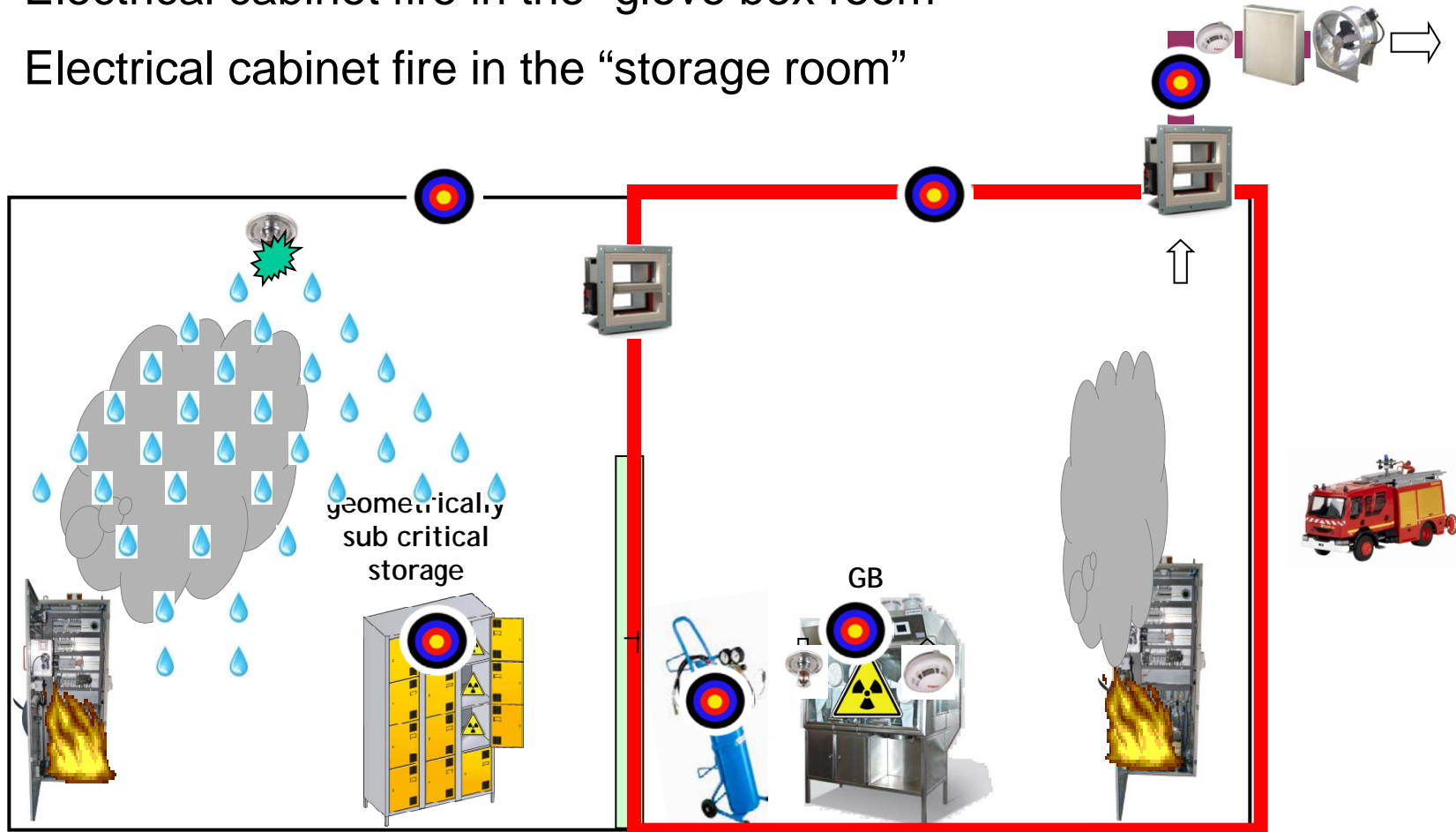
- Result of computer codes
 - Zone models
 - CFD models
 - ...
- Expert advice
- Feedback



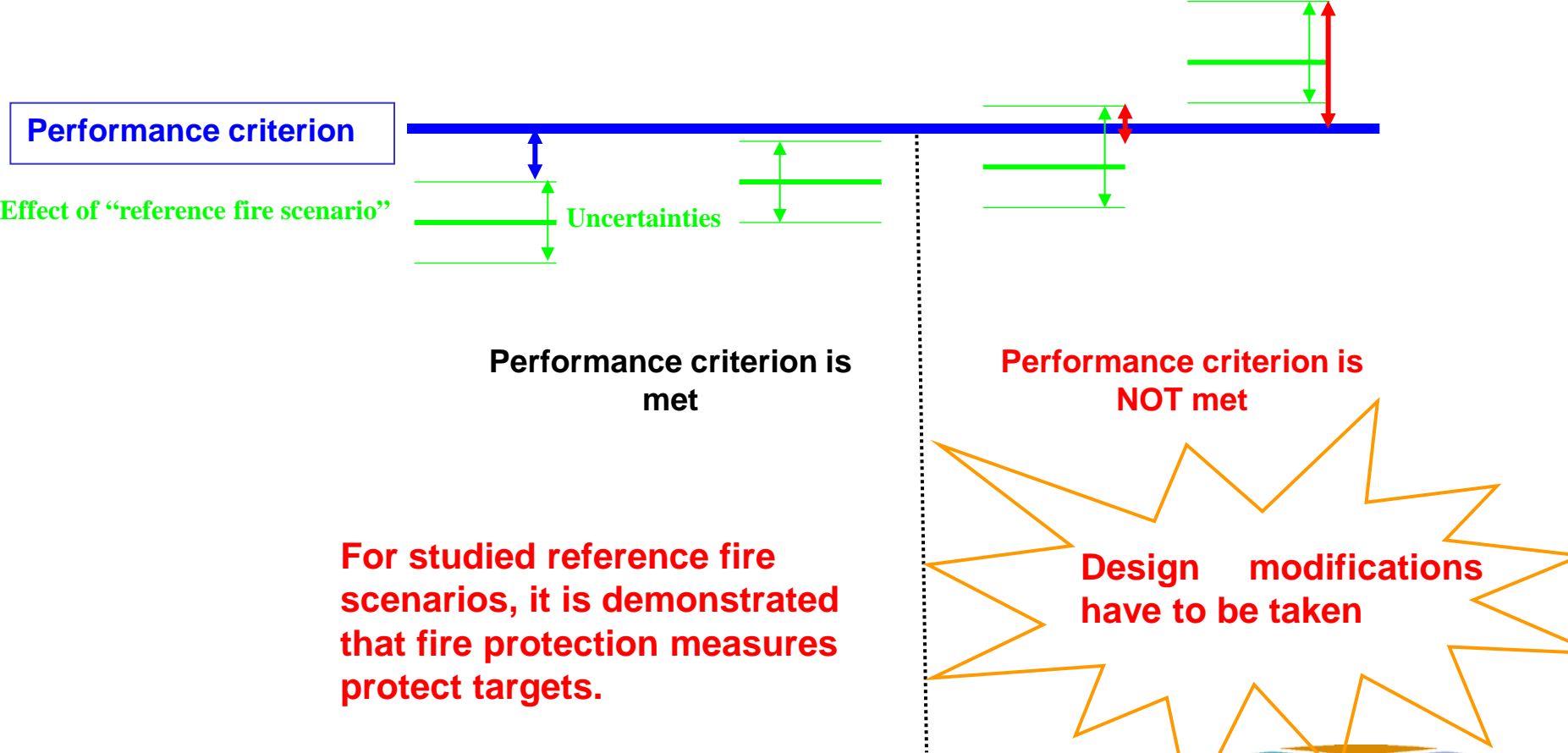


Determining if design meets performance criteria

- Electrical cabinet fire in the “glove box room”
- Electrical cabinet fire in the “storage room”



Determining whether design meets performance criteria



Determining if design meets performance criteria

- Storage room

- Performance criteria*
 - Sub critical storage
 - 400 °C : safe geometry
 - Room structure
 - (T°, t) : structure resistance
- Fire scenario effects* = 50 °C :
 - **performance criteria are met**

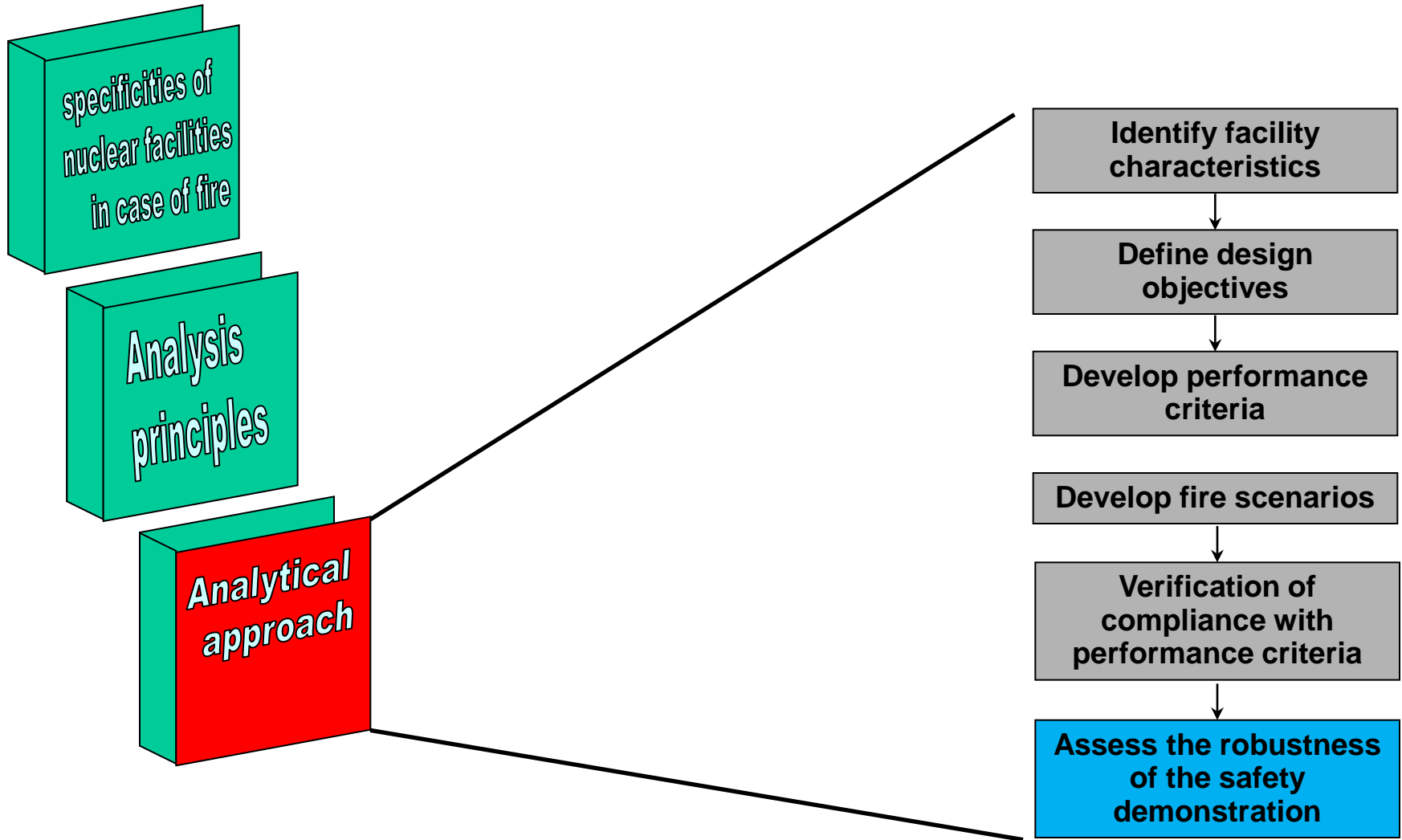
- Glove box room

- Performance criteria*
 - Target 1: gloves box (nuclear containment)
 - 100 °C, 2 kW/m²
 - Target 2: dynamic containment system
 - 180 °C, ΔP(filter)=1800 Pa
 - Target 3: room structure
 - fire thermal flux < walls thermal flux resistance
- Fire scenario effects*
 - **70 °C ; 0,5 kW/m² -> GB performance criteria are met**
 - **150 °C (fire code) ; 1000 Pa (test) -> DC performance criteria are met**
 - **Structure performance criteria are met**

All performance criteria are met

For studied reference fire scenarios, it is demonstrated that fire protection measures protect targets

* Fictitious values

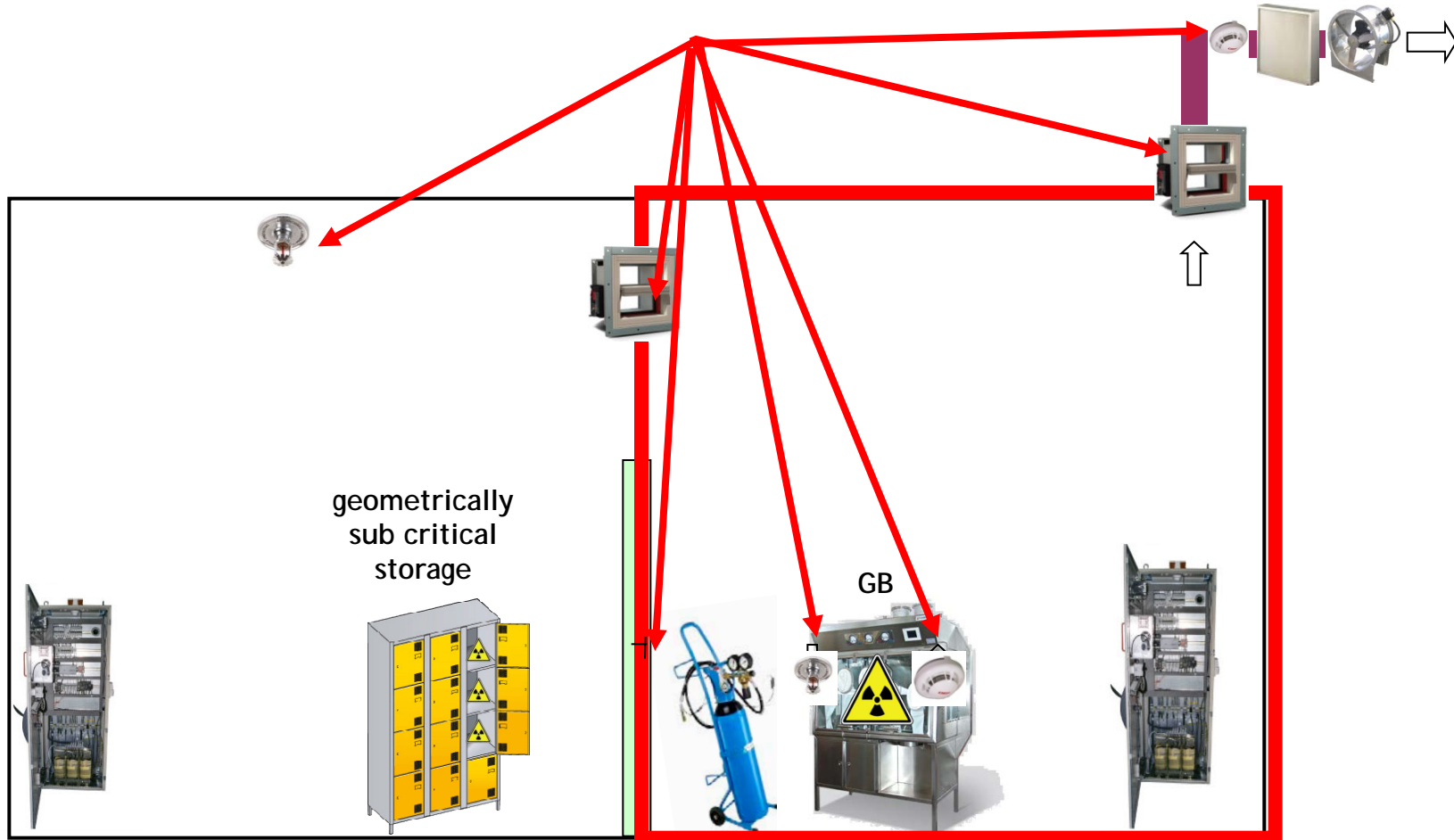


Assess the robustness of the safety demonstration

- The failure of fire protection measures can lead to fire scenarios more severe than design fire scenarios.
 - So, performance criteria can not be respected.
- This stage consists in checking the robustness of the safety demonstration by making sure that the consequences for safety remain acceptable in spite of:
 - 1) Failure of a fire protection measure
 - Deterministic approach
 - Probabilistic approach
 - 2) “Worst case fire scenarios” = automatic systems fail and fire brigade does not respond.

Assess the robustness of the safety demonstration

- Study the consequences of a fire with each passive or active fire protection system individually rendered ineffective



Assess the robustness of the safety demonstration

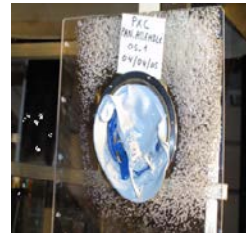
- Storage room*

- Performance criteria
 - Sub critical storage
 - 400 °C : safe geometry
 - Room structure
 - (T°, t) : structure resistance
- Fire scenario effects = 300 °C (sprinkler failure) :

Performance criteria are met despite fire protection failure

- GB room*

- Performance criteria
 - Dynamic containment system
 - 180 °C, $\Delta P(\text{filtre})=1800 \text{ Pa}$
 - Gloves box (containment)
 - 100 °C, 1 kW/m²
 - Room walls
 - (T°, t) : walls integrity
- Fire effects in case of one fire protection failure



- 180 °C (fire tools), 1000 Pa (test) : « dynamic containment » criteria are met
- 300 °C : « GB » criteria are not meet (GB extinguishing system failure)

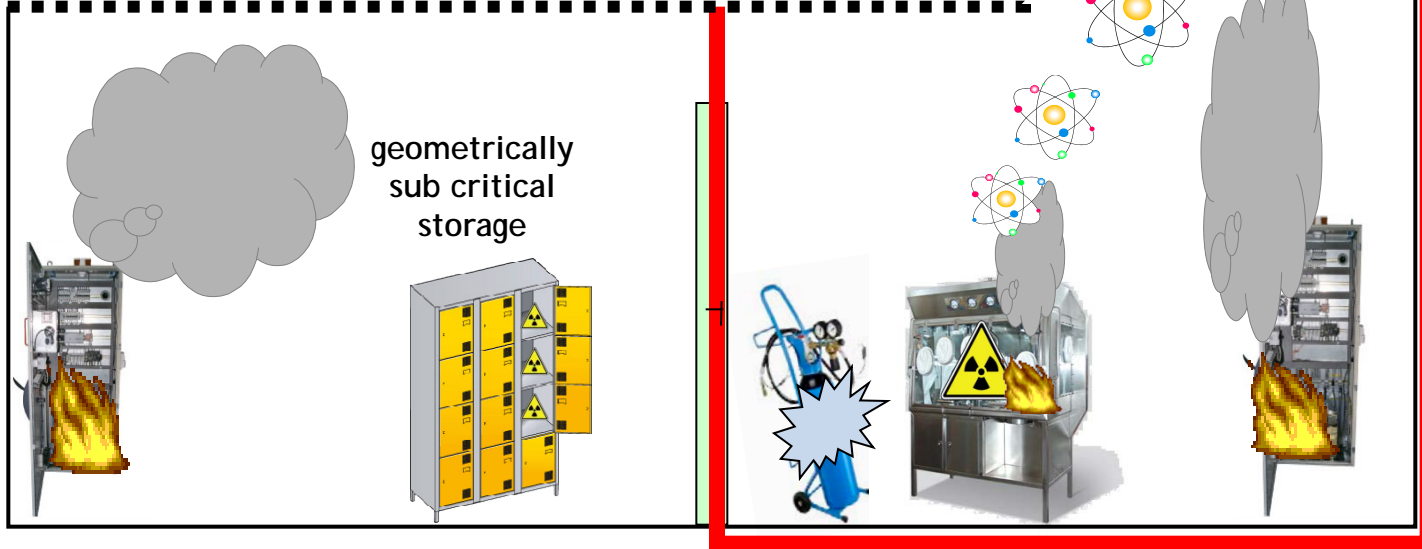
If the consequences are not acceptable, design modifications have to be taken

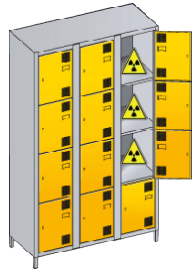
Assess the robustness of the safety demonstration

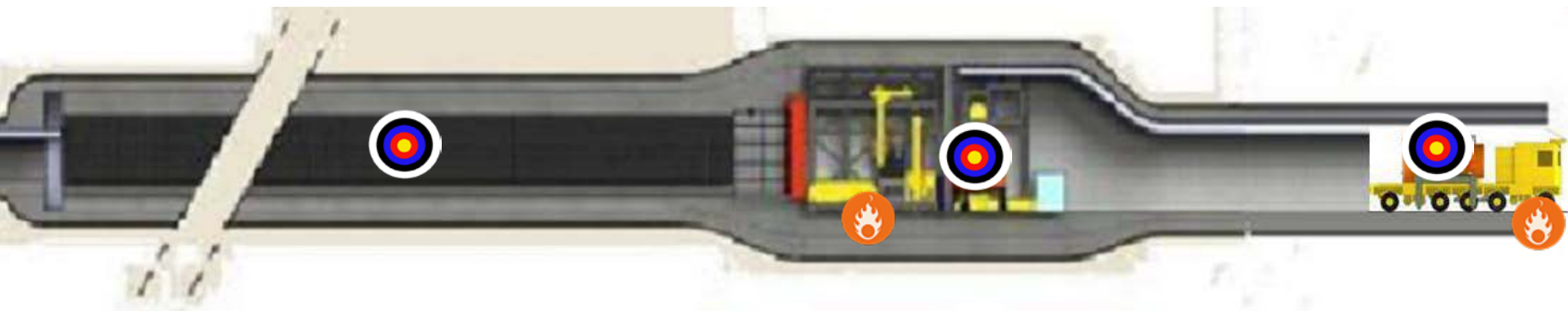


Worst case fire scenarios

- If the consequences are not acceptable, design modifications have to be taken
- If the consequences are considered to be tolerable, the safety demonstration in the event of a fire is acceptable







CONCLUSION

Process for fire safety analysis

- There is a progression in this analysis process
 - Basic fire scenarios
 - Reference fire scenarios
 - Degraded fire scenarios
 - Failure of fire protection measures
 - Worst case fire scenarios
- Defense in depth approach
 - Several levels of protection => several levels of analysis

CONCLUSION

- Fire protections measures should be implemented according to a defense in depth approach
- Principles to include in a safety demonstration:
 - Defense in depth approach
 - Consider all the states of operation of the facility
 - Safety margins
 - Consider combined events
 - Use appropriate models...

The prediction of fire phenomenon is complex

Thank you for your attention

