Hyindoor

Pre normative research
on the indoor use of fuel cells and hydrogen systems

Safety objectives, phenomena and consequences map

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New Energy World JU
fuel cells & hydrogen for sustainability

Ulster University

Safety objectives of hydrogen use indoors

Three generic safety objectives

There are three generic safety objectives for any safety system including for use of hydrogen systems indoors:

- **Life Safety**
- Property protection
- Environment protection

Primary consideration should be given to life safety, including site workers, customers and general public.

Examples of life safety objectives

The life safety objectives may include, but not limited to:

- The occupants are able to leave building/facility in reasonable time
- Consequences to occupants are acceptably low
- First responders are able to operate in reasonable safety
- Collapse or debris does not endanger bystanders, first responders and other people likely to be near facility

Harm criteria for humans are presented in Appendix 1.1 of the Guidelines.

Owners and regulators involvement

Along life safety facility owners should consider reduction of damage to infrastructure to minimise disruption of business, preserve corporate image and reduce direct/indirect financial losses.

Attention should be paid to preventing the escalating effects, and to value and importance of the property in and around a facility.

Regulators should be involved in the estimation of environment impact from accidents for:

a) Prevention of significant damage to neighbouring facilities and reduction of “domino effect”

b) Limit adverse effects on the natural environment, such as asphyxiation and cold burns on fauna and flora, etc.

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Hydrogen safety engineering

Hydrogen safety engineering

- Hydrogen Safety Engineering (H2SE) is defined as the application of scientific and engineering principles to the protection of life, property and environment from adverse effects of incident/accidents involving hydrogen.
- It is paramount to ensure that H2SE is taken into account at the earliest possible stage, preferably during the design of the system or infrastructure.

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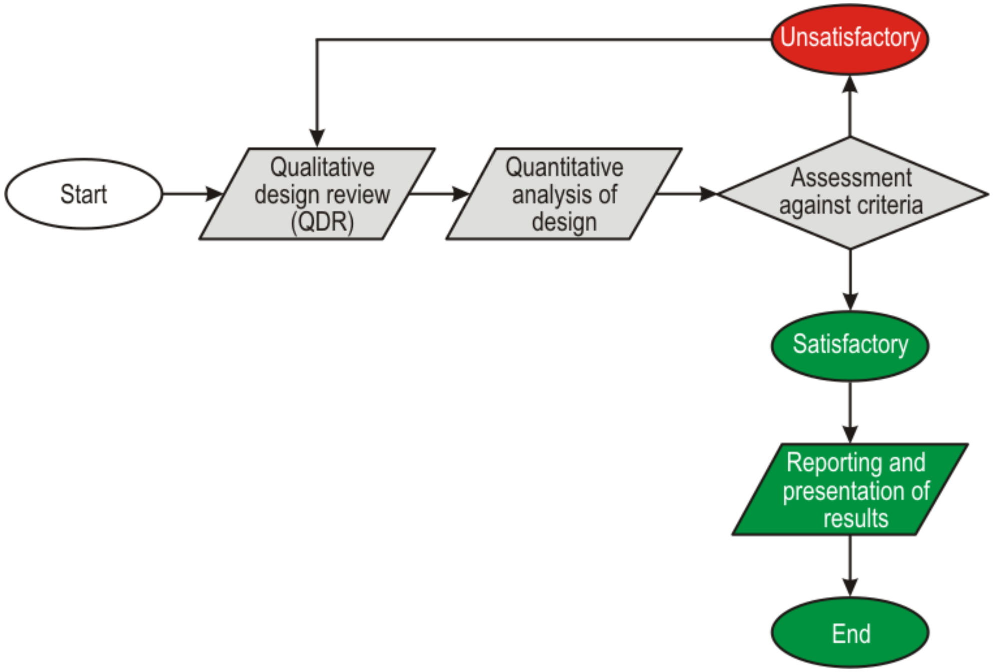
Hydrogen safety engineering

H2SE involves three main steps or procedures:

a) Qualitative Design Review (QDR) - team

b) Quantitative Analysis – engineer

c) Assessment against criteria – engineer



Hydrogen safety engineering

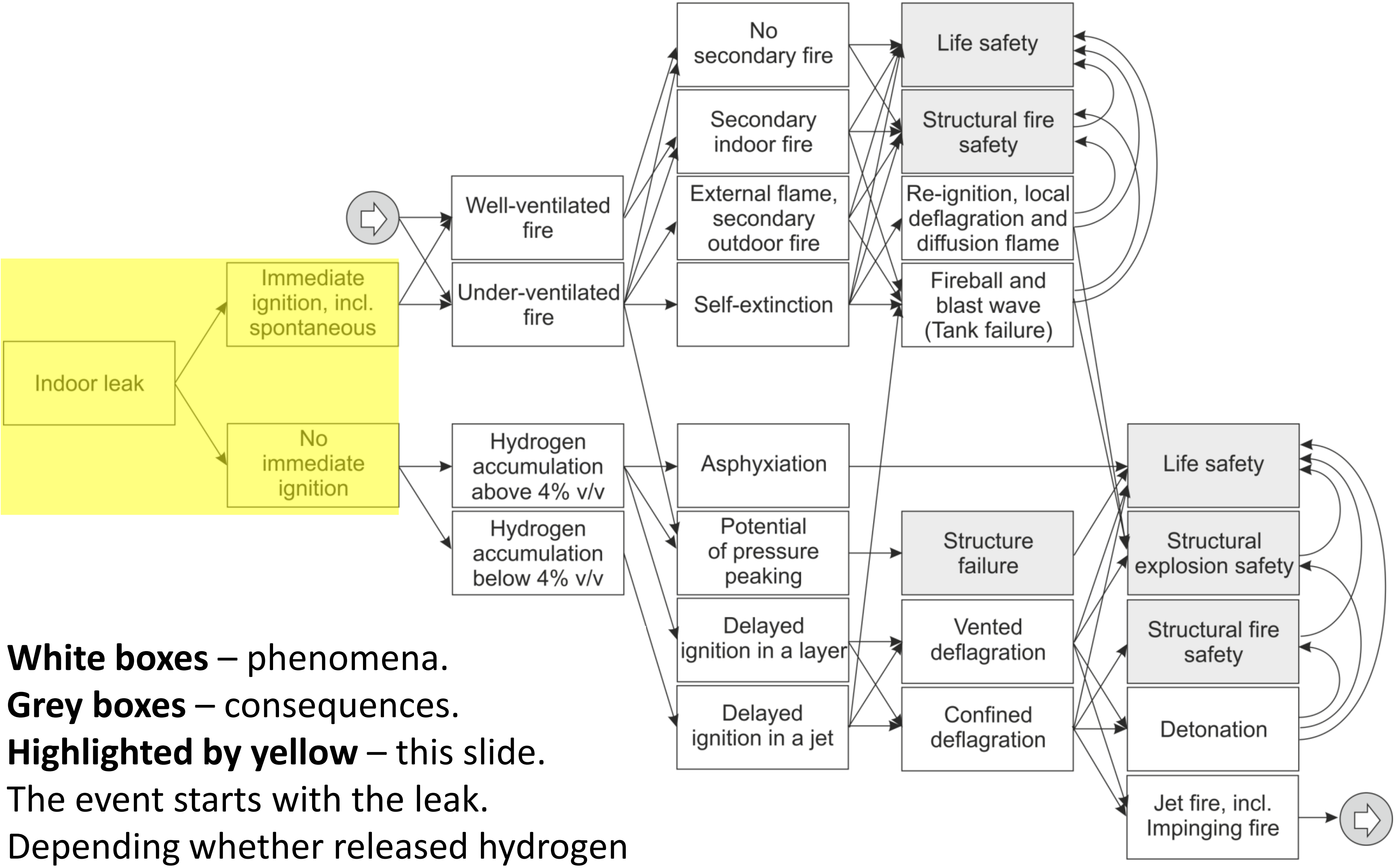
- QDR is a qualitative process based on the experience and knowledge of design team. QDR has to be carried out early in the design process and in a systematic way, so that any substantial findings and relevant items can be incorporated in the design
- Quantitative analysis is performed by hydrogen safety expert(s) following the QDR carried out by the team to ensure that the problems are fully understood and that the analysis addresses the relevant aspects of the hydrogen safety system or infrastructure; and to simplify the problem and minimize the calculation effort involved.

Hydrogen safety engineering

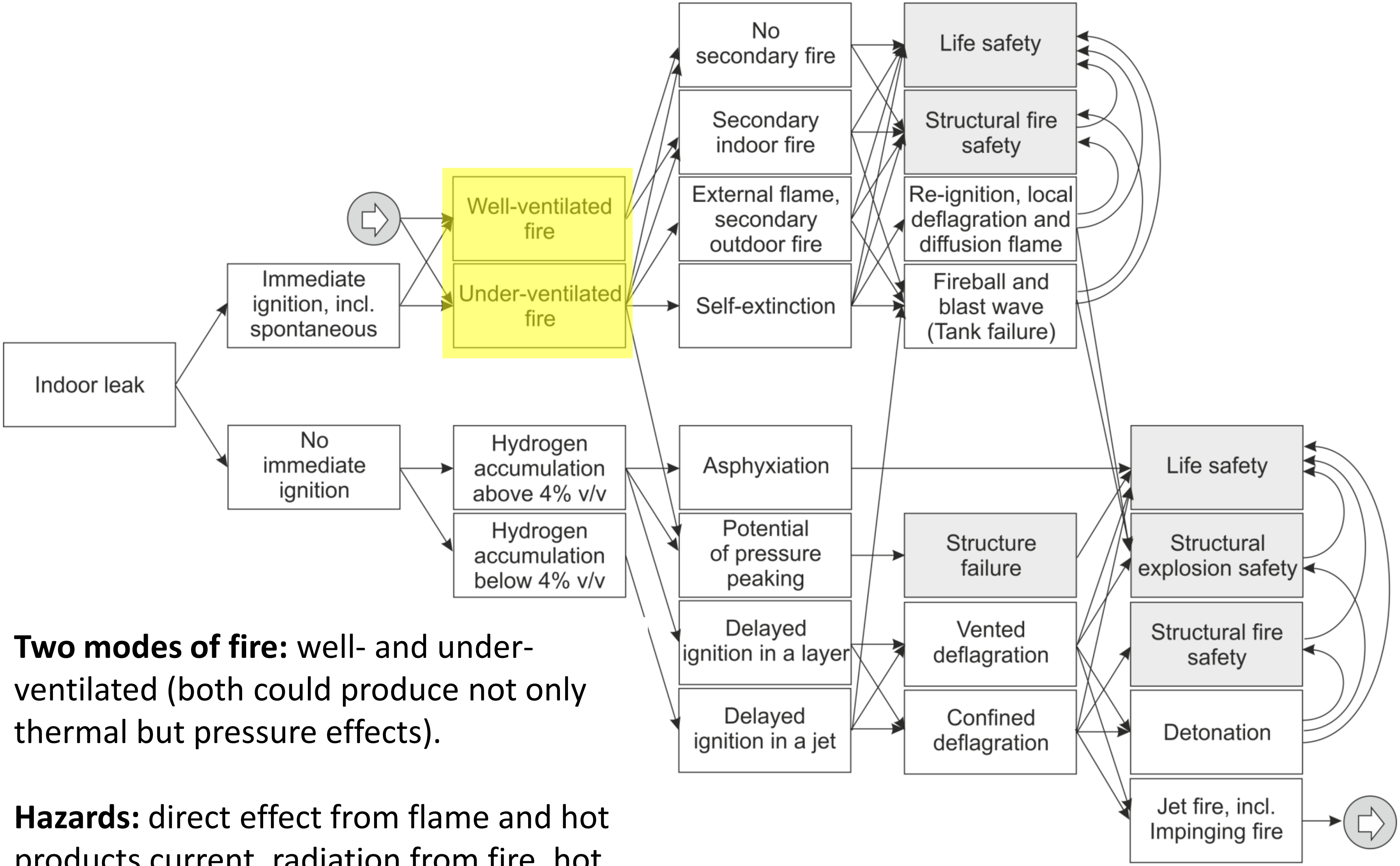
Following quantitative analysis, the results should be compared with the acceptance criteria identified by the team during QDR exercise. Three basic types of approach can be considered:

- Deterministic approach, which shows that on the basis of the initial assumptions a defined set of conditions will not occur;
- Comparative approach, which shows that the design provides a level of safety equivalent to that in similar systems and/or conforms to pre-existing codes;
- Probabilistic approach, which shows that the risk of a given event occurring is acceptably low (very expensive to apply in full, was “never” done in full for hydrogen).

Phenomena and consequences map

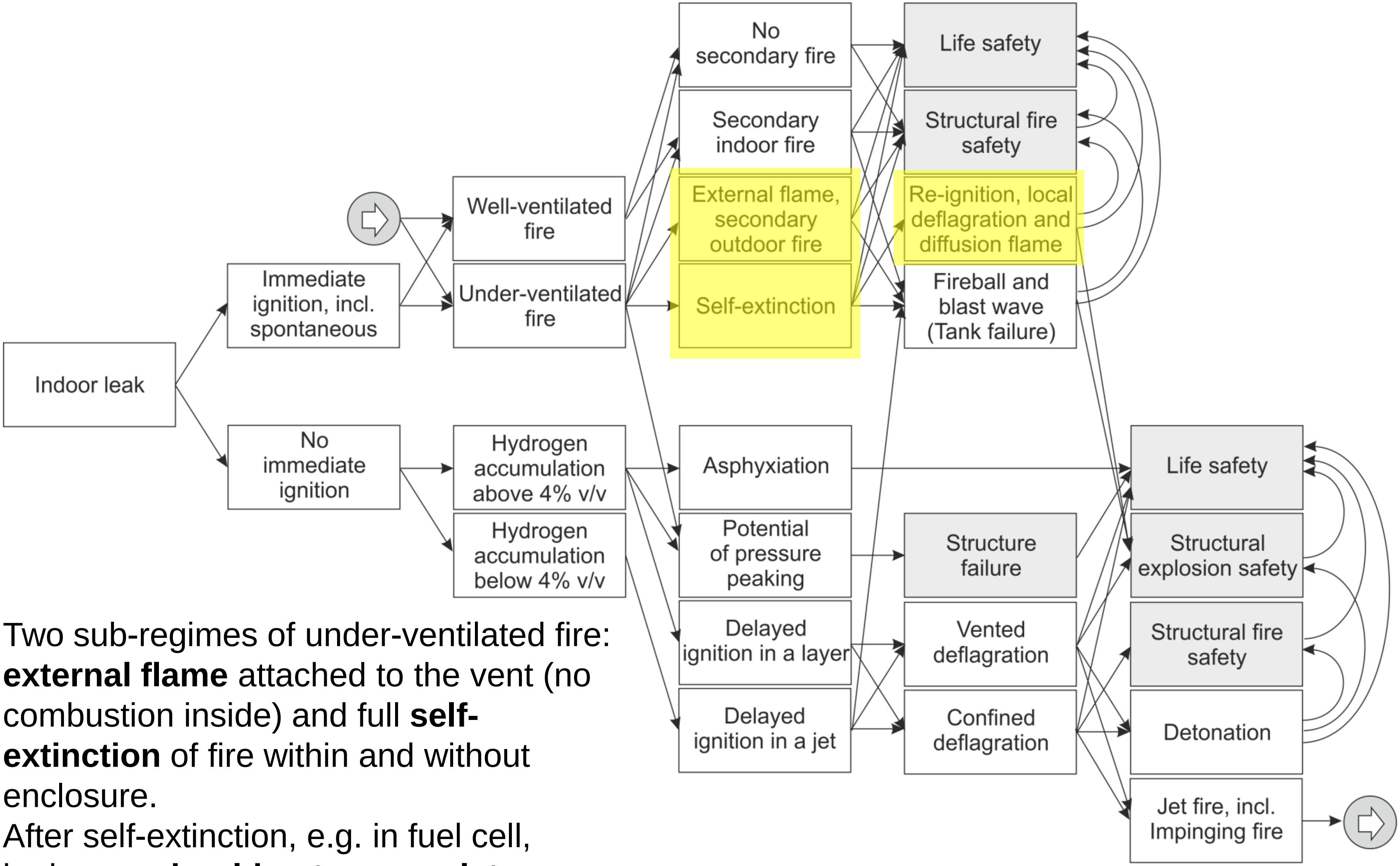


White boxes – phenomena.
Grey boxes – consequences.
Highlighted by yellow – this slide.
The event starts with the leak.
Depending whether released hydrogen ignites immediately upon release, subsequent development can follow two possible scenarios.



Two modes of fire: well- and under-ventilated (both could produce not only thermal but pressure effects).

Hazards: direct effect from flame and hot products current, radiation from fire, hot layer and the ceiling, structural failure of load bearing construction elements due to flame impingement, secondary fire, etc.



Indoor leak

Immediate ignition, incl. spontaneous

No immediate ignition

Well-ventilated fire

Under-ventilated fire

Hydrogen accumulation above 4% v/v

Hydrogen accumulation below 4% v/v

No secondary fire

Secondary indoor fire

External flame, secondary outdoor fire

Self-extinction

Asphyxiation

Potential of pressure peaking

Delayed ignition in a layer

Delayed ignition in a jet

Life safety

Structural fire safety

Re-ignition, local deflagration and diffusion flame

Fireball and blast wave (Tank failure)

Structure failure

Vented deflagration

Confined deflagration

Life safety

Structural explosion safety

Structural fire safety

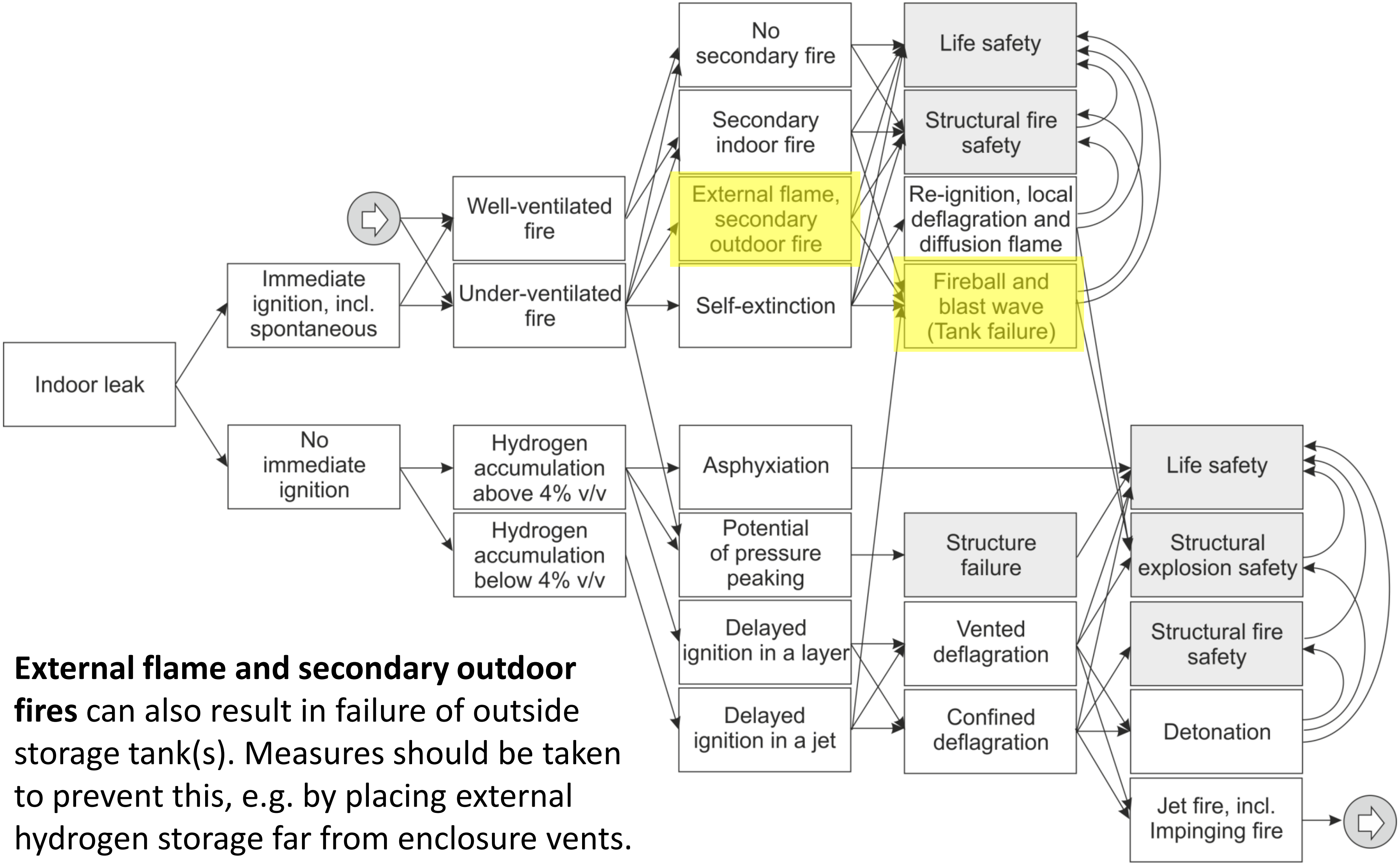
Detonation

Jet fire, incl. Impinging fire

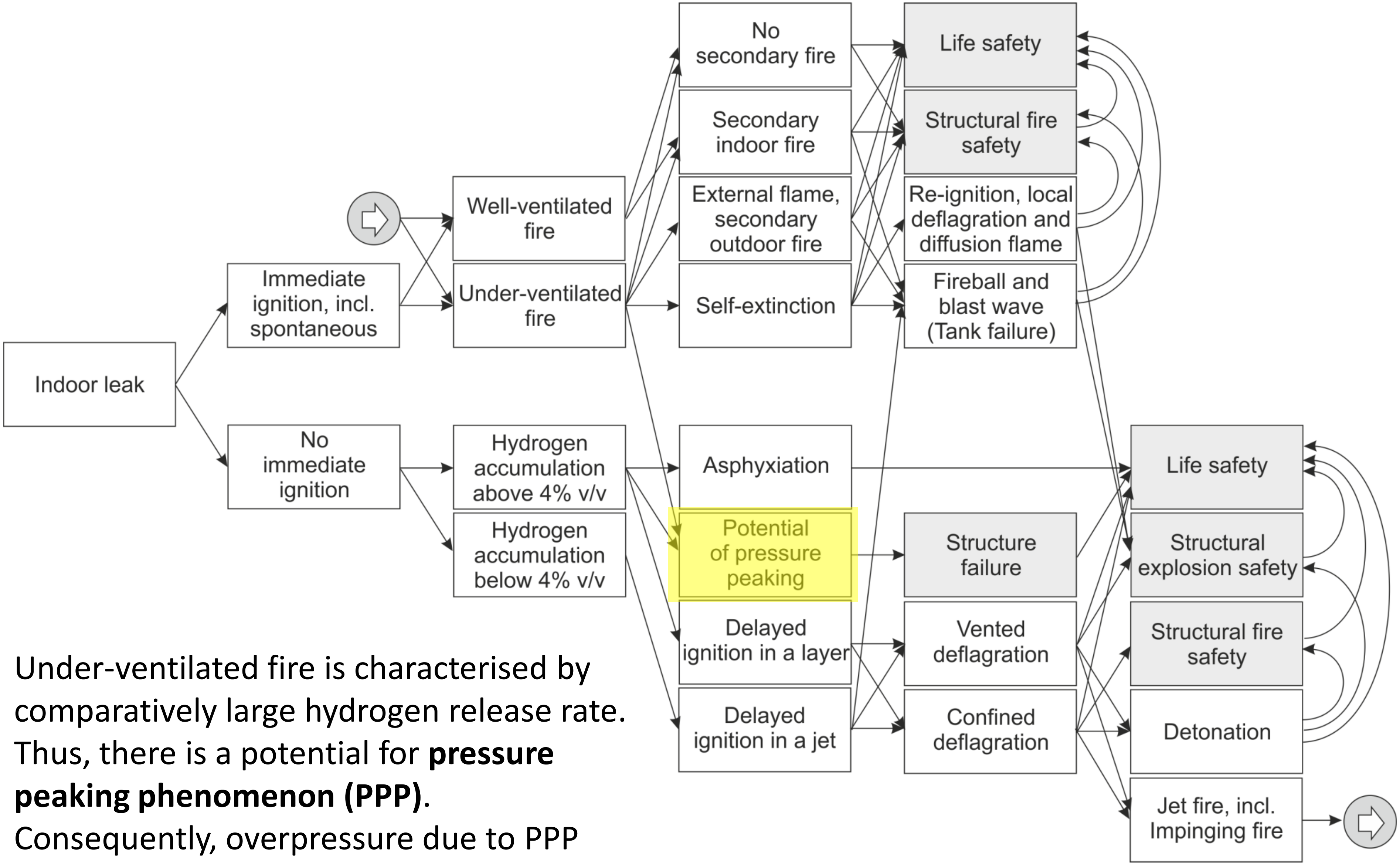
Two sub-regimes of under-ventilated fire: **external flame** attached to the vent (no combustion inside) and full **self-extinction** of fire within and without enclosure.

After self-extinction, e.g. in fuel cell, hydrogen **should not accumulate** above LFL in the enclosure with FC.

There is **re-ignition** potential for under-ventilated fire.



External flame and secondary outdoor fires can also result in failure of outside storage tank(s). Measures should be taken to prevent this, e.g. by placing external hydrogen storage far from enclosure vents. Primary and secondary fires can lead to a failure of storage tank, resulting in **fireball** and **blast wave**.



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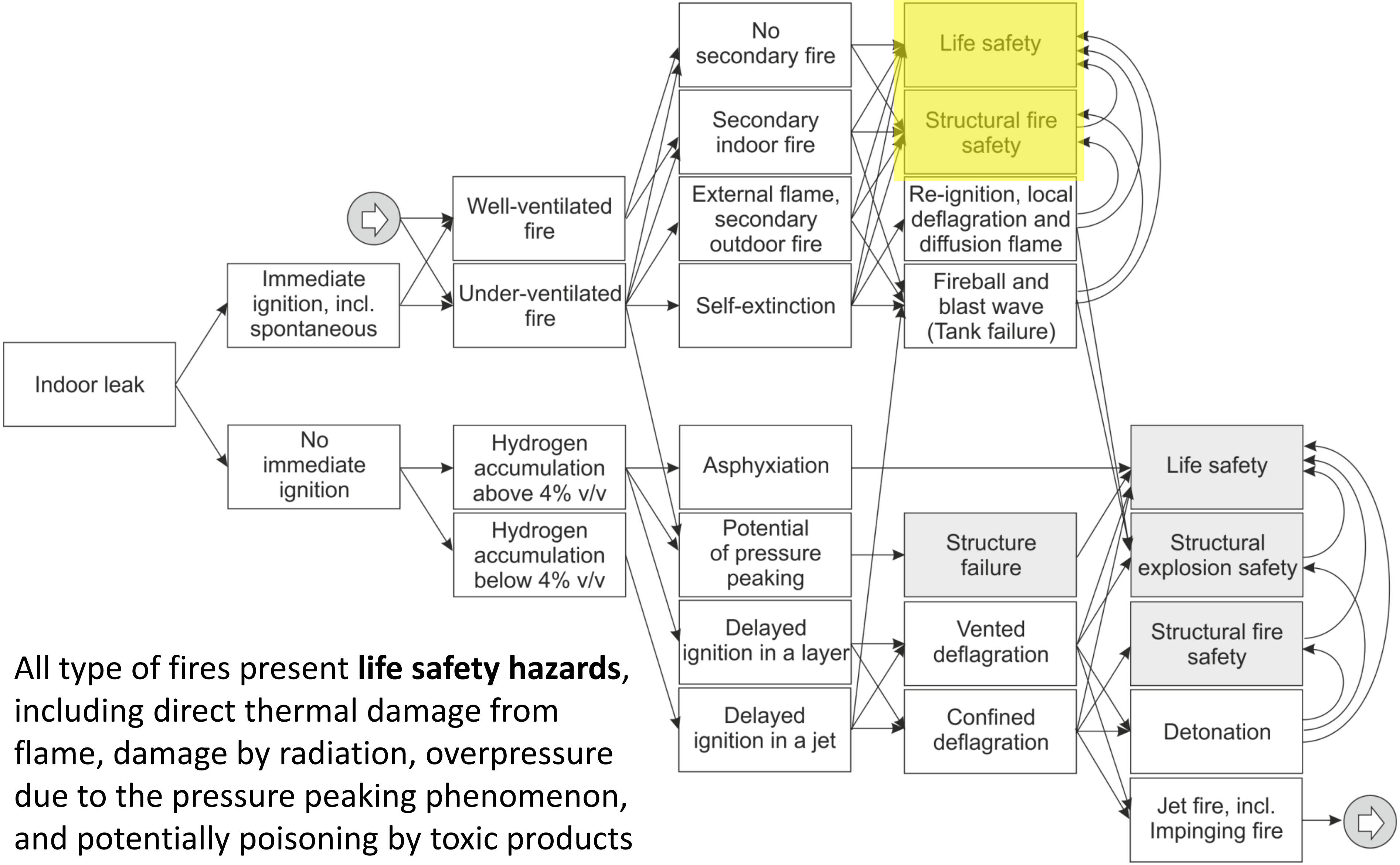
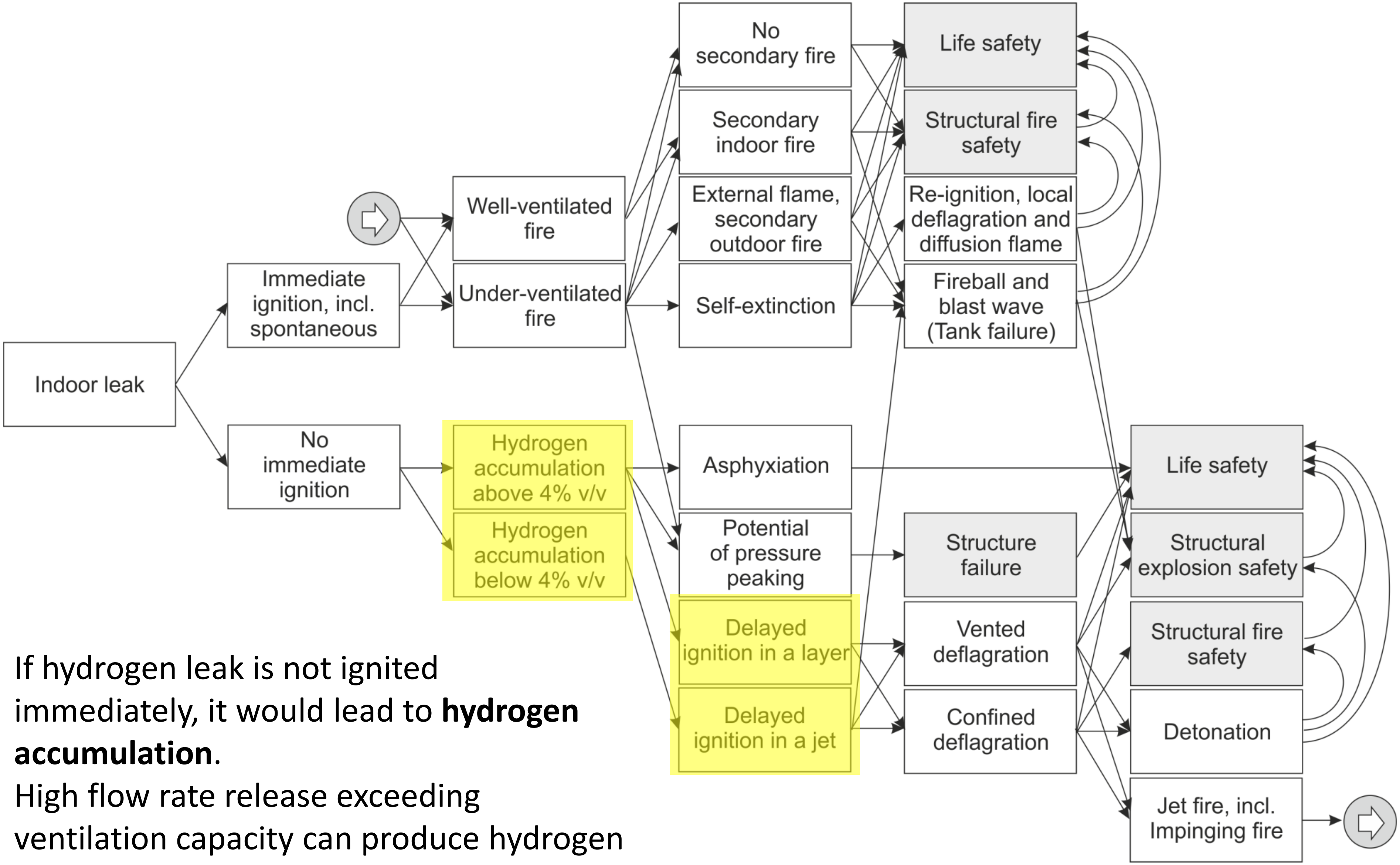
Under-ventilated fire is characterised by comparatively large hydrogen release rate. Thus, there is a potential for **pressure peaking phenomenon (PPP)**. Consequently, overpressure due to PPP should be assessed (Appendix 2.1). Ignited release will generate higher overpressure due to PPP compared to unignited release.



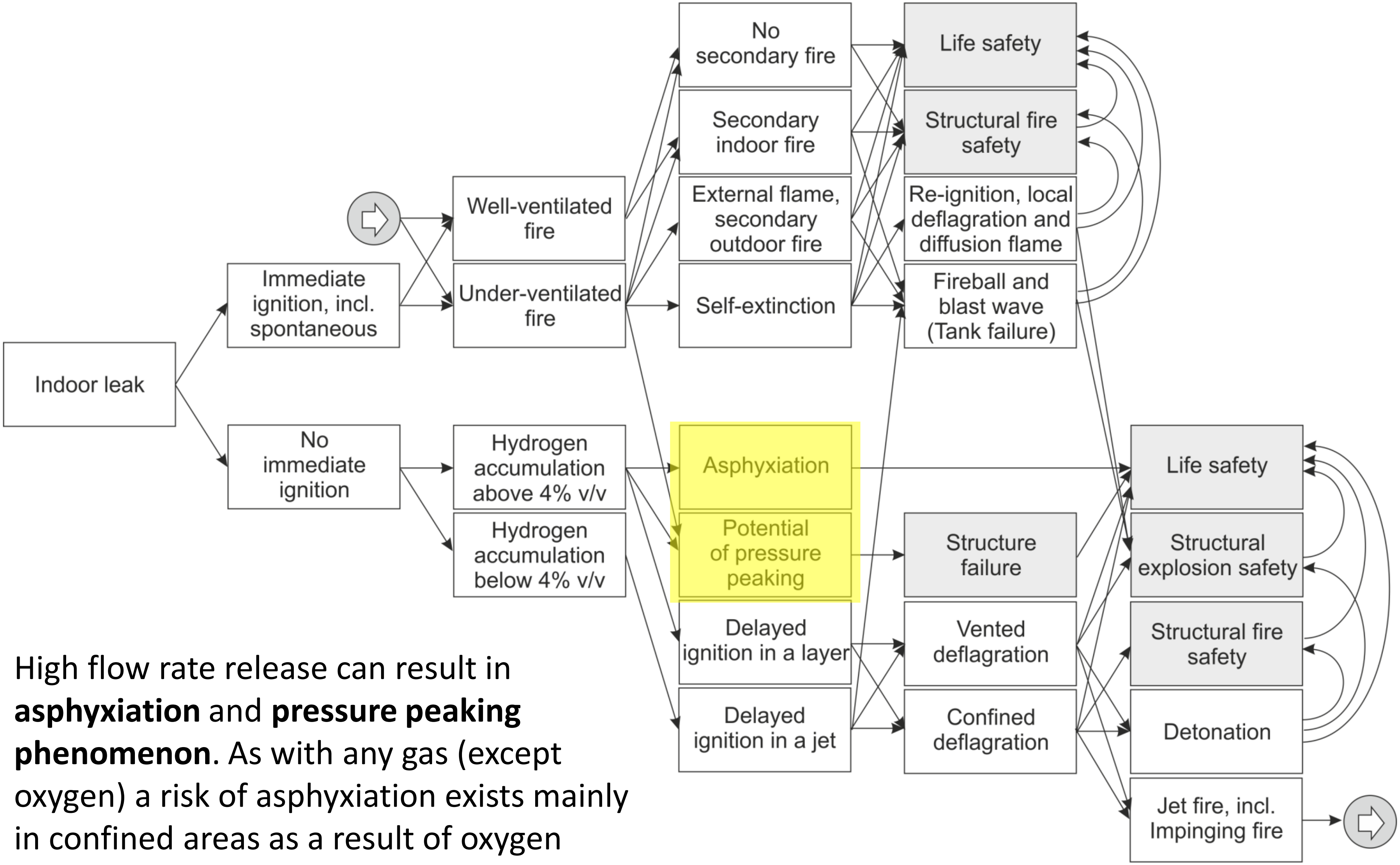
All type of fires present **life safety hazards**, including direct thermal damage from flame, damage by radiation, overpressure due to the pressure peaking phenomenon, and potentially poisoning by toxic products produced by a secondary fire.

Fires of all types also present **structural fire safety hazard**.



If hydrogen leak is not ignited immediately, it would lead to **hydrogen accumulation**.

High flow rate release exceeding ventilation capacity can produce hydrogen **concentration exceeding 4%** by volume, i.e. LFL, which creates possibility for **delayed ignition and deflagration**.



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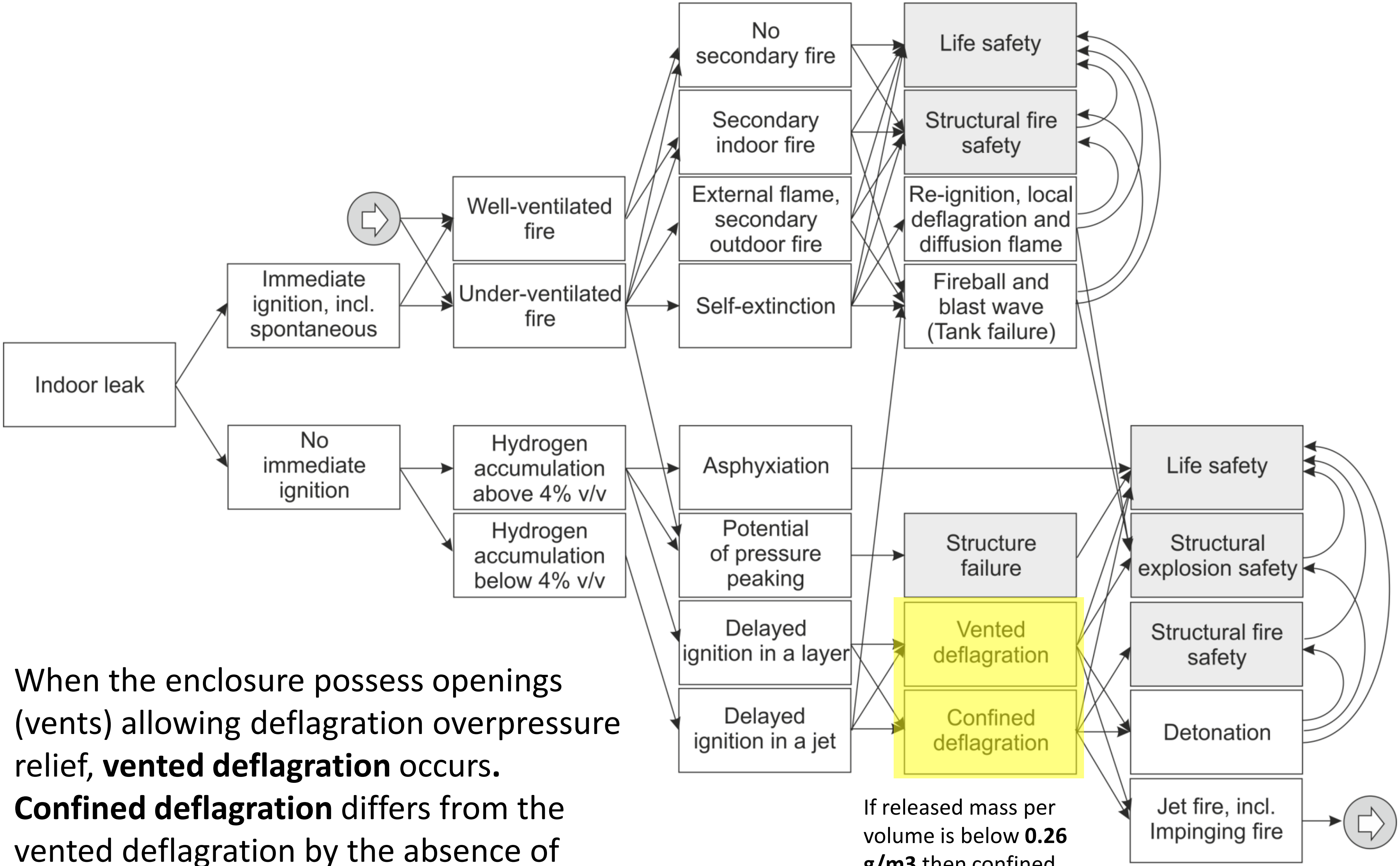
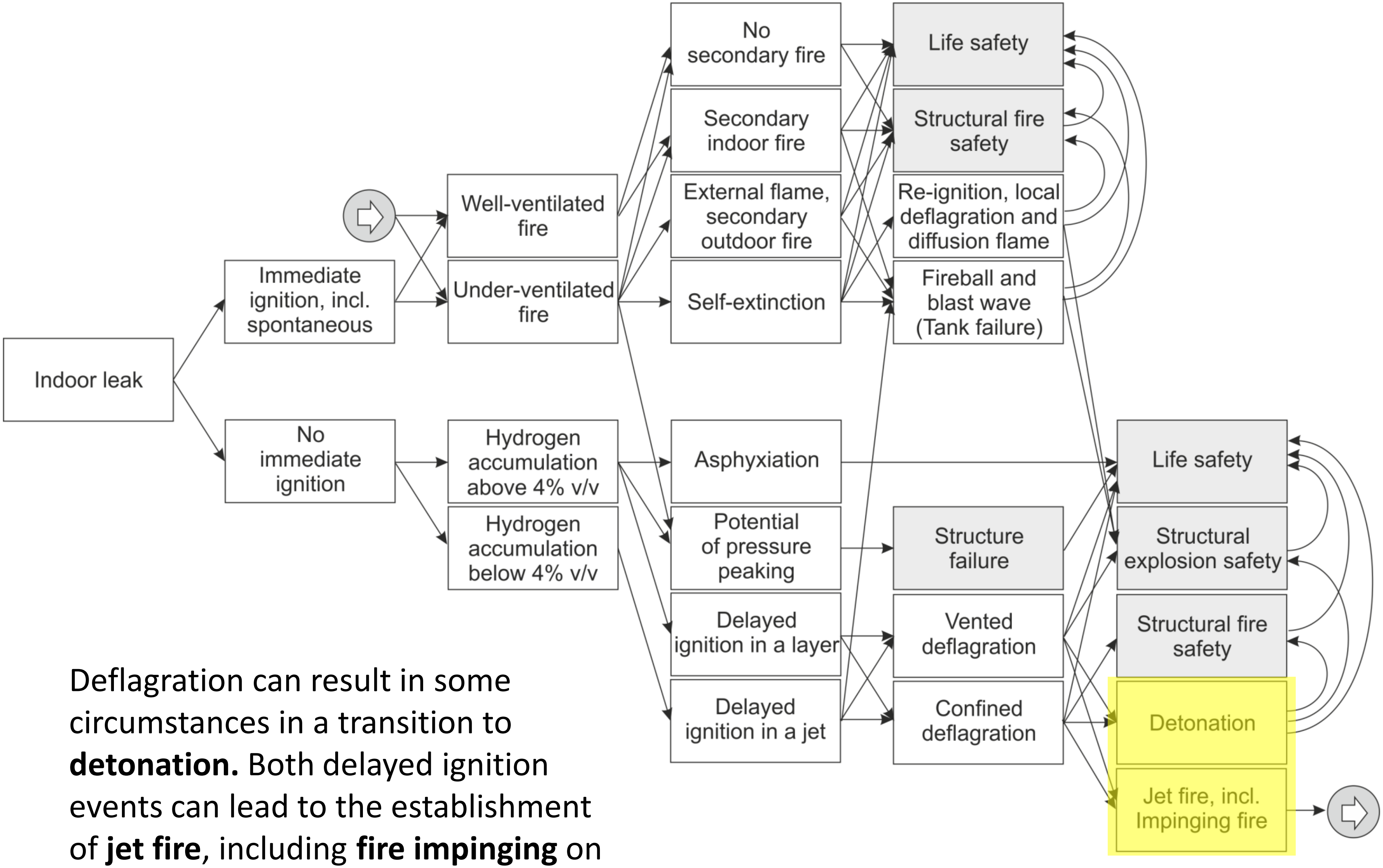
High flow rate release can result in **asphyxiation** and **pressure peaking phenomenon**. As with any gas (except oxygen) a risk of asphyxiation exists mainly in confined areas as a result of oxygen depletion (ISO/TPRD 15916, 2008). **Proper ventilation system should exclude any life threat including asphyxiation.**

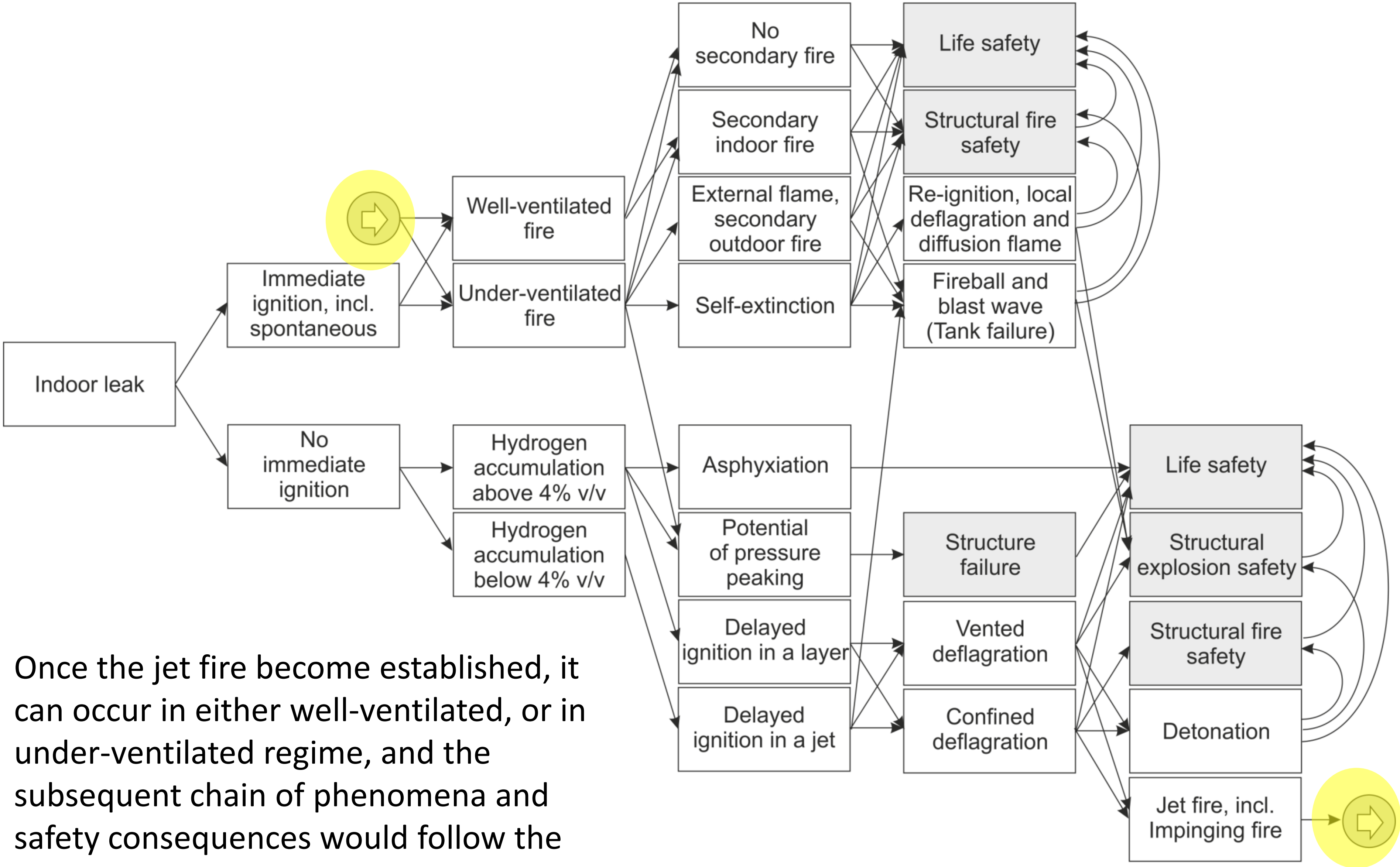


When the enclosure possess openings (vents) allowing deflagration overpressure relief, **vented deflagration** occurs**.** **Confined deflagration** differs from the vented deflagration by the absence of significant openings leading to the atmosphere.

If released mass per volume is below **0.26 g/m3** then confined deflagration can have only minor damage to enclosure (windows, etc.)



Deflagration can result in some circumstances in a transition to **detonation.** Both delayed ignition events can lead to the establishment of **jet fire**, including **fire impinging** on the wall and/or ceiling of the enclosure.



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Once the jet fire become established, it can occur in either well-ventilated, or in under-ventilated regime, and the subsequent chain of phenomena and safety consequences would follow the pattern depicted in **immediate ignition** branch of the map, as illustrated by arrow in a circle pictograms.

THANK YOU

Acknowledgment to FCH JU for funding HyIndoor project (www.hyindoor.eu)