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MINISTÈRE DE LA DÉFENSE

# New IM issue on naval platforms: Solid Rocket Motor (SRM) pneumatic explosion risk. Effects prediction methodology

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**Tucson, Arizona May 11-14**

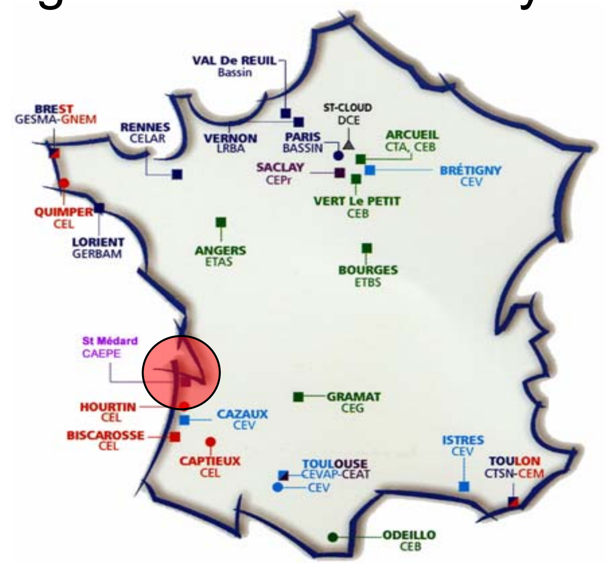
DGA

DÉLÉGATION GÉNÉRALE POUR L'ARMEMENT

# DGA and CAEPE

- DGA = Armament Procurement Agency of the French MoD

  DGA missions:
  - Preparing the future of defence systems
  - Equipping the armed forces
  - Promoting defence equipment export
- DGA operates its own test centres for "Testing and evaluating materials"
- CAEPE is the DGA Propulsion Testing and Missile Safety centre
  - Located near Bordeaux
    - 330 people
    - 10 ground testing facilities
    - 3000 ha
    - 2000 tests carried out in 35 years

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DGA

# CAEPE: DGA Propulsion Testing and Missile Safety centre

- Our missions:
  - Testing and expertise:
    - Performance of propulsion systems for either strategic or tactical missiles
    - Ageing of propulsion systems
    - Safety assessment for propulsion system, ammunition and complete weapon system
  - Contractors support:
    - Assembling of propulsive stages for the French ballistic missiles

- Safety assessment:
  - Safety testing areas: all IM tests
  - Expertise division: simulations, technical support, IM tests interpretation

# Introduction: Solid Rocket Motor explosion, The new risk of naval safety studies

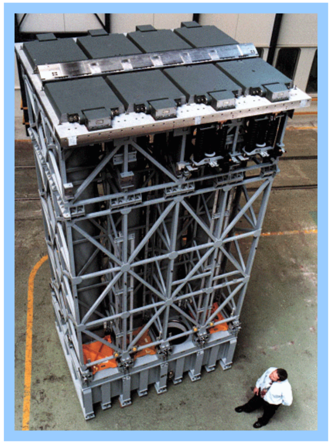
- IM munitions suppress ~~mass detonation~~ risk
- Naval hazard analysis highlight a new risk considering the high density of ammunition on board:

  **Solid Rocket Motor explosion risk**
- Consequences of the risk: catastrophic (death of personnel, loss of the ship if sympathetic reactions)
- Different causes of explosion:
  - at ignition
  - during firing
  - due to accidental or combat threats
- Accurate assessment of explosion consequences necessary to:
  - Mitigate the risk
  - Meet system requirements

# Introduction: Solid Rocket Motor explosion, The new risk of naval safety studies

- Specific configuration: SRM explosion in Vertical Launch System:
  SRM ignition in the ship → explosion in the VLS magazine

- Two main issues:
  - Sympathetic reaction?
    ↳ Ammunition reaction scenario
  - Ship integrity threatened?
    ↳ Thermal and pressure loadings



- Development of a new methodology based on simulations to deal with this ship confined configuration.

- Explosion effects divided and studied in 3 steps:
  I. Fragments projection
  II. Blast overpressure
  III. Fire due to scattering of burning propellant fragments

# I. Fragment projections

**Study of fragment impacts on adjacent munitions and risk of initiation associated**

- Fragmentation computed thanks to CRONOS (in-house analytical code)

- CRONOS: designed to delimit hazard areas generated by SRM explosion. Calculates:

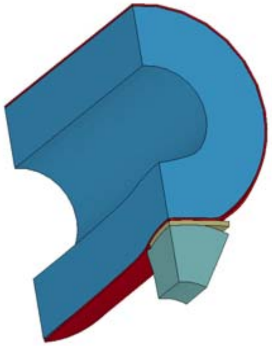
| | | |
|---|---|---|
| Fragment size distribution | Probabilities of hitting or killing | |
| Initial velocities | Heat fluxes | 5 hazard areas |
| Flight trajectories | Air blast overpressure | |

- CRONOS used in our study to determine fragment size distribution and evaluate initial velocities

# I. Fragment projections

- CRONOS fragmentation: input of Ls-Dyna code study to predict initiation risk

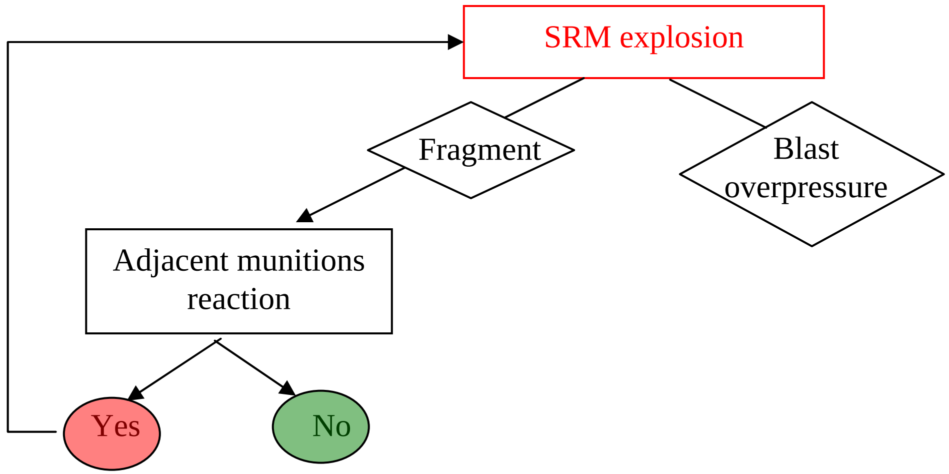
- Fragment impacts directly adjacent missile



*Fragment impact – Fragment position for v=0m/s*

- Conclusion on initiation: casing perforation or energy criteria

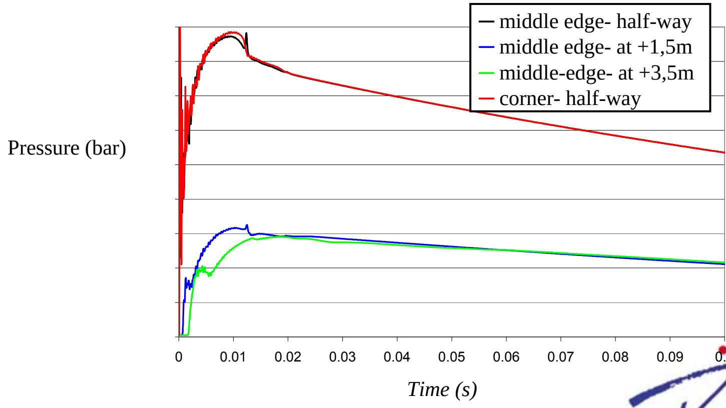
# Effects prediction methodology



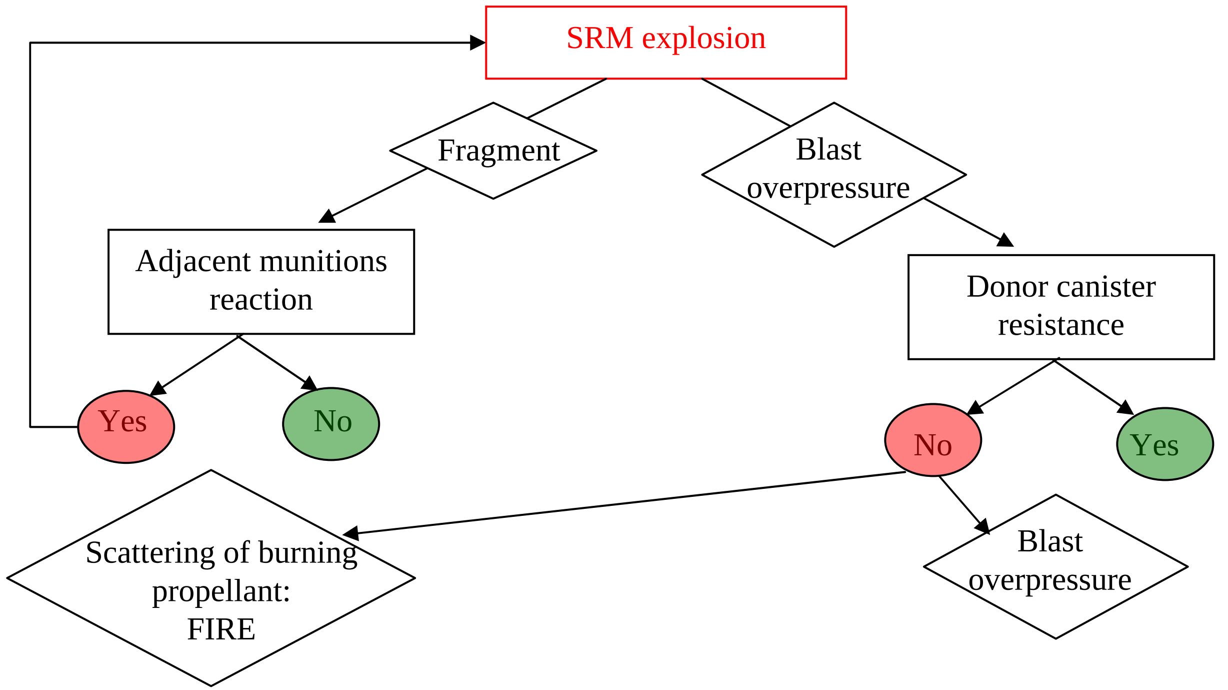
# II. Blast overpressure effect
# Effect on donor canister

## Study of blast effect on donor canister resistance

- Blast overpressure propagation simulated by CFD code Fluent
- Explosion modeled by a shock tube phenomenon: a pressurised hot gas volume released in its environment
- 3D model computes pressure loadings on the internal canister surface:
  - $P0 = P_{structure\ failure}$
  - $V0 = V_{free}$
  - Gas production amplified by the sudden enlargement of the combustion surface. This gas production is injected in the initial hot gas volume
- Conclusion on canister resistance:
  Comparison with canister failure value



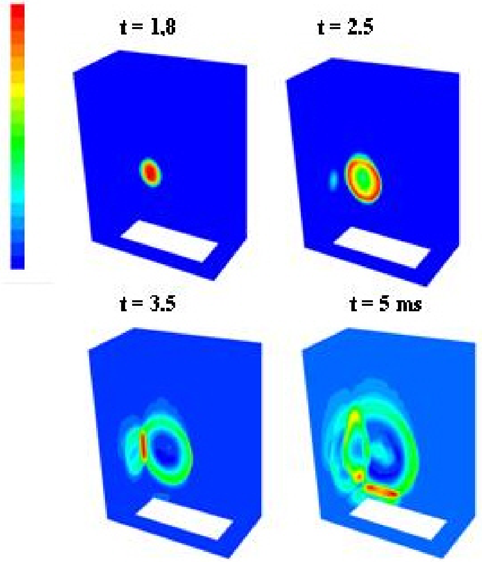
# Effects prediction methodology



# II. Blast overpressure effect
## Effect on VLS magazine and adjacent munitions

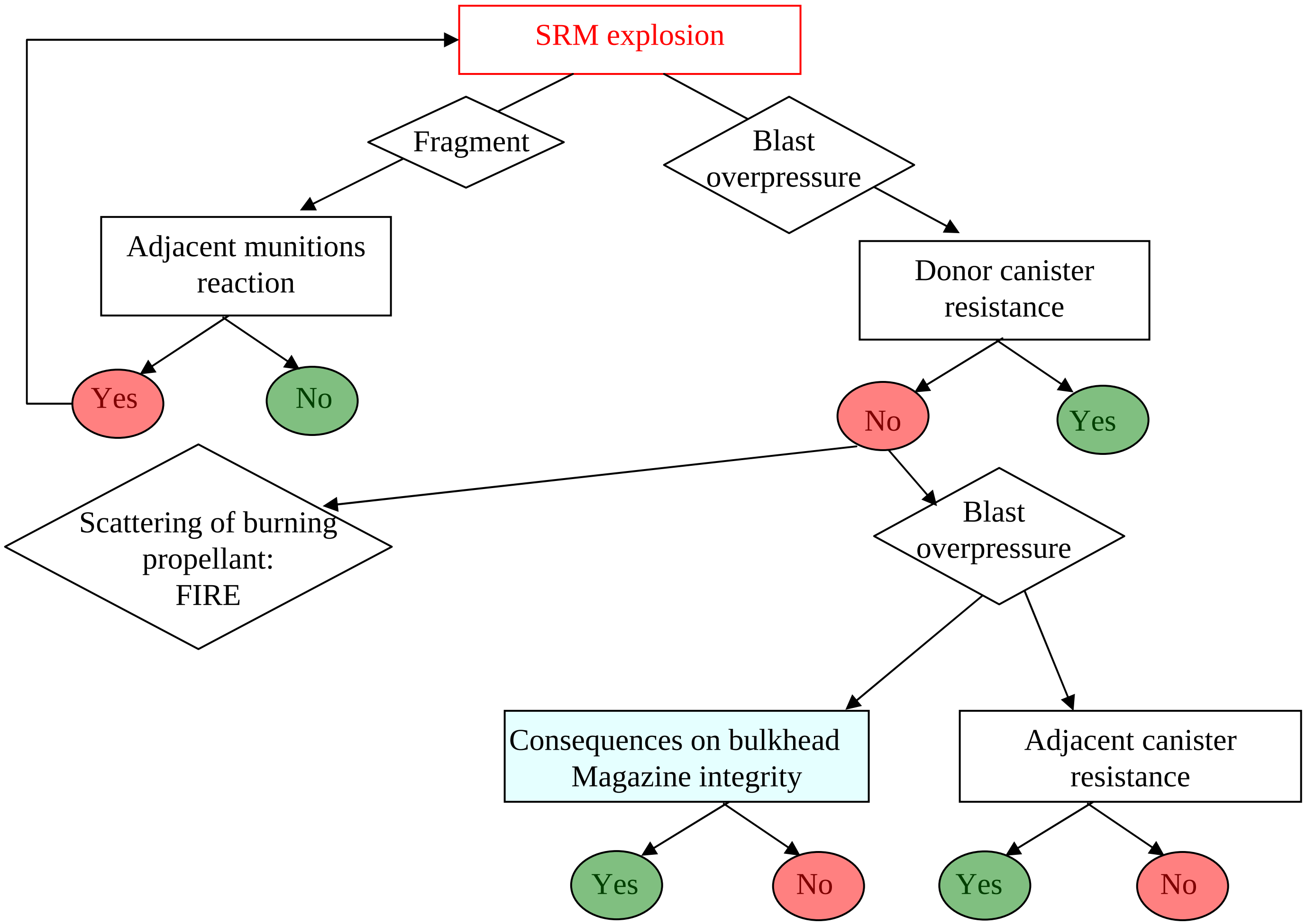
**Study of the non-stationary pressure loadings on bulkheads and on adjacent canisters and determination of canister resistance**

- 3D model of the magazine operated to model the pressure wave propagation
- Shock tube phenomenon:
  - Canister break-up effects are neglected
- Simulation computes time-dependent blast overpressure in every point in the magazine
- Important influence of the donor missile site in the magazine
- Conclusion:
  - Blast overpressure time-dependent mappings on bulkhead and adjacent canisters
  - Adjacent canister resistance: Comparison with canister failure value or Ls-Dyna simulation



*Blast overpressure time-dependent mappings on the magazine bulkheads*

# Effects prediction methodology



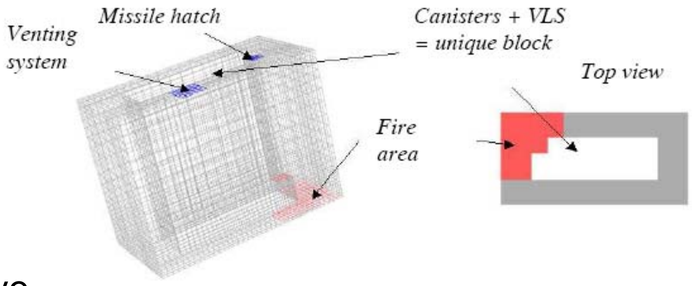
# III. Fire due to scattering of burning propellant fragments

**Study of quasi-static pressure evolution and heat flux from propellant fire to canister and magazine bulkhead**

- 3D model runs with Fluent, taking into consideration venting systems.
- Choice of Fluent: possibility to compute heat radiation and to take into account sonic outflow by venting systems.
- Choice of 3D model: necessity to identify local maxima of heat transfer (important for adjacent munitions initiation risk)

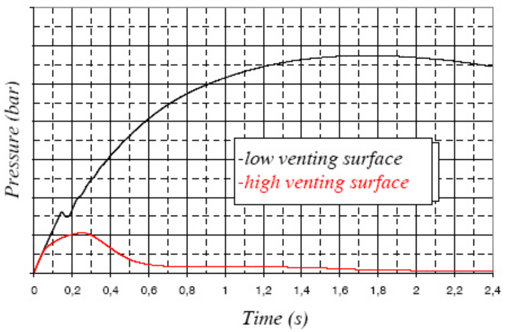
- Gas flow rate during fire determined thanks to CRONOS fragmentation combustion surface and pressure-dependent combustion velocity.

- Geometry considered:
  - Fire area limited next to the exploded missile:
  overvalue of pressure and heat flux→ safety at stake
  - Simplified geometry to limit calculation time:
  gas do not flow between canister,
  exchange volume and surface reduced→ conservative

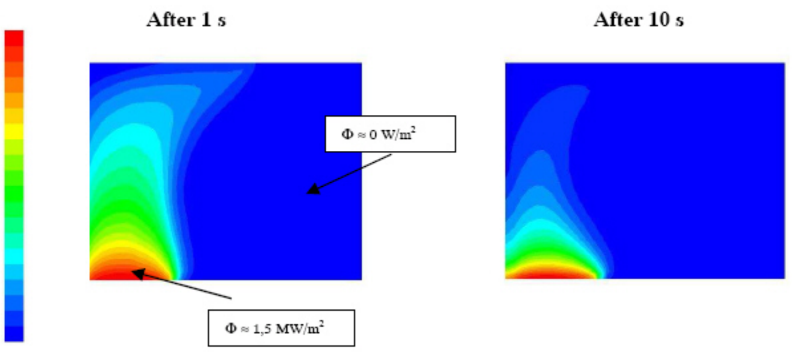


# III. Fire due to scattering of burning propellant fragments

- Results: Quasi-static pressure quickly uniform in the magazine
- Quasi-static pressure evolution:

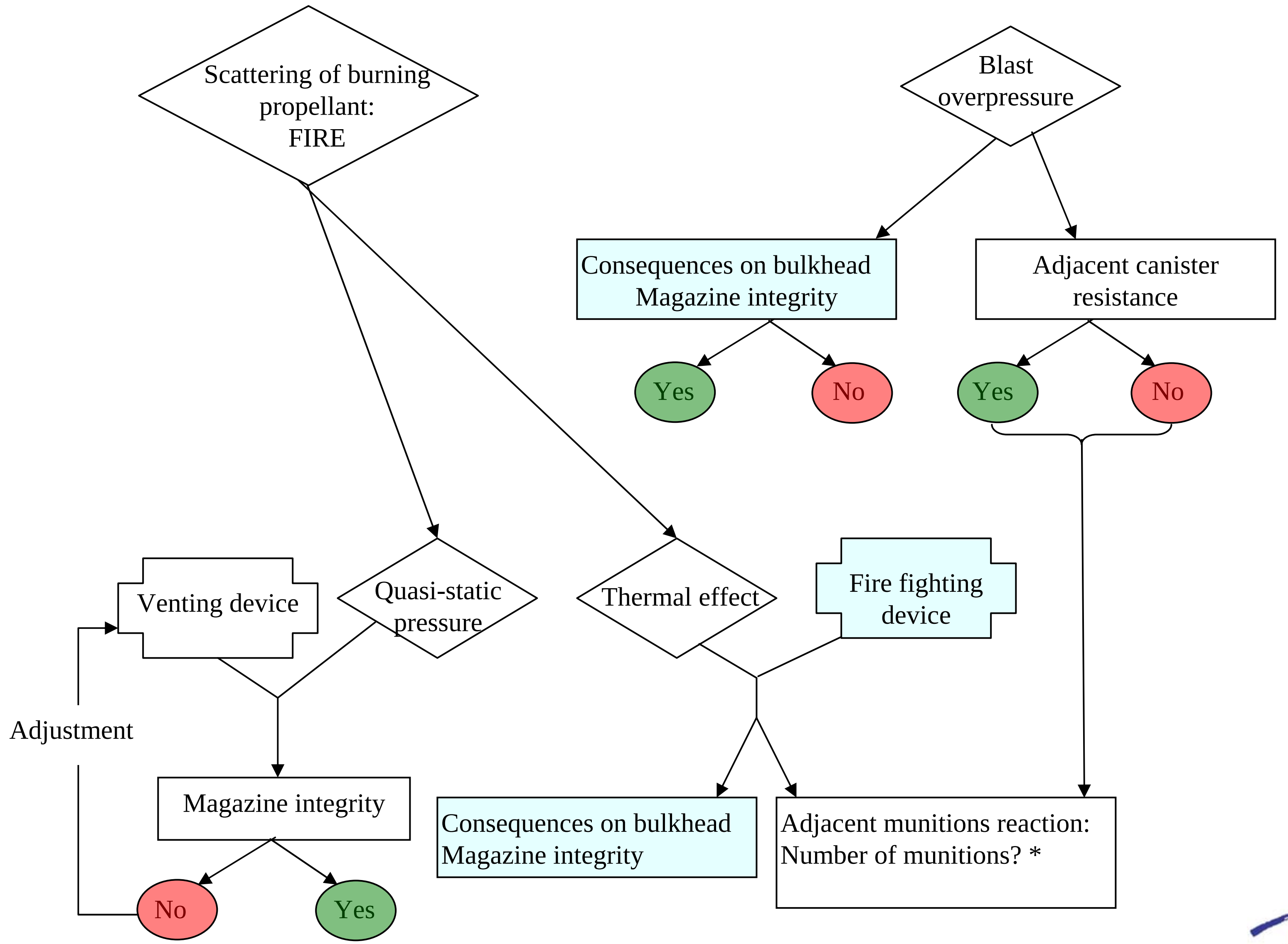



- Result shows efficiency of venting device
- Heat flux mapping on bulkhead (shows 3D aspect of thermal phenomenon):




- Conclusion:
  - Quasi-static pressure evolution: adequation of venting device implemented
  - Heat fluxes to determine bulkhead and adjacent missile temperature evolution

# Effects prediction methodology



# IV. Adjacent missiles reaction risk evaluation

## Study of adjacent missiles temperature evolution and reaction risk associated

- 1D model is used:
  - Conduction in canister
  - Radiation between canister and missile
  - Convection between air in canister and missile and canister walls
  - Conduction in different missile materials
- Inputs of 1D model: heat fluxes computed thanks to the 3D fire model
- Reaction missile criterion: reaching fast cook-of ignition temperature in the propellant.

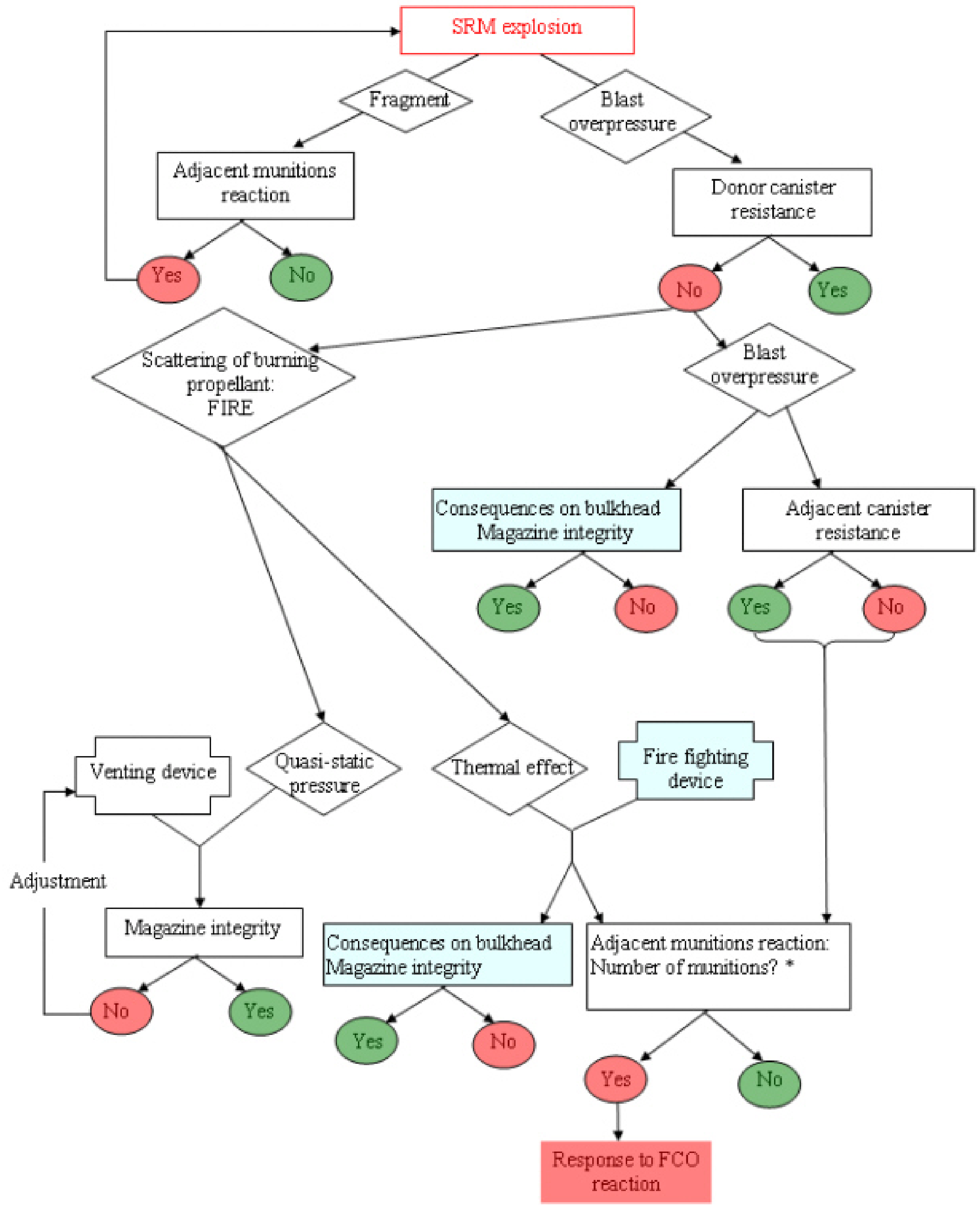
# IV. Adjacent missiles reaction risk evaluation

- Outputs: adjacent missile ignition delay. Real difference between immediately adjacent munitions and others.

- To state on sympathetic reaction risk: comparison between ignition delay and fire fighting device initiation delay, taking into account its efficiency.

- If adjacent munitions reaction acknowledge, FCO SRM response: new missile reaction.

- Conclusion: construction of the whole reaction missile scenario.


SRM explosion
Fragment
Blast overpressure
Adjacent munitions reaction
Donor canister resistance
Yes
No
No
Yes
Scattering of burning propellant: FIRE
Blast overpressure
Consequences on bulkhead Magazine integrity
Adjacent canister resistance
Yes
No
Yes
No
Venting device
Quasi-static pressure
Thermal effect
Fire fighting device
Adjustment
Magazine integrity
Consequences on bulkhead Magazine integrity
Adjacent munitions reaction: Number of munitions? *
No
Yes
Yes
No
Yes
No
Response to FCO reaction

# Conclusion

- Methodology explores the large range of SRM explosion effects.
- Tackles the 3 types of threats associated to SRM explosion:
  - Mechanical threats:
    - Fragment projection
    - Blast overpressure
  - Thermal threats:
    - Fragment burning
- Use of CFD code: relevant choice for this confined magazine configuration. Good approach of blast wave with reflection phenomenon and thermal effects with local maxima identification
- Study outputs various:
  - To assess reaction risk of adjacent munitions. Whole reaction scenario in VLS magazine consequently to SRM donor explosion can be drawn up
  - To assess VLS magazine and ship integrity. The on-board consequences: object of another study conducted by CTSN (DGA centre)

**The methodology provides strong elements to achieve an accurate assessment of the safety level of VLS integrated on board.**

# Any questions ?

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