# A PARTNERSHIP BETWEEN RENAULT AND FRENCH FIRST RESPONDERS TO ENSURE SAFE INTERVENTION ON CRASH OR FIRE-DAMAGED ELECTRICAL VEHICLES.

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## ABSTRACT

In order to ensure first Responder safety, Renault set up a collaborative approach to involve rescuers in our electrical vehicle conception. The breakthrough came from the integration of crash and fire deterioration from the earliest stages of vehicle development.

Collaboration with fire brigades revealed 5 key areas which were then dealt with: electrical vehicle identification; prevention of electrical risk during emergency intervention; the impact of Li Ion batteries on occupant extrication and fire; co-creation of decision-making tools (Emergency Response Guide or ERG, rescue cards); training sessions on electrical vehicles.

EV prototypes were provided to study how the 400V system affected fire brigade intervention. Extrication tests were led on the full range of Renault electrical vehicles to take into account the different locations of the 400V battery. Fire tests were carried out until total combustion of the 400V batteries was reached. Then, extinction tests in open and closed environments were conducted, led by French scientific laboratories. Temperatures, thermal radiation, and concentrations of flue gases effluents were measured in most of these tests.

A large number of electrical vehicles were donated to French and European fire brigades for extrication training and fire demonstration. Bespoke electrical vehicles were produced as training supports and offered to fire brigades.

Trainings are given for free to French rescuers all around the year by an engineer from Renault, expert in electrical vehicle interventions.Finally, Renault regularly participates in national working groups with fire brigades and contributes to the ISO initiative on ERG writing and templates.

This combination of actions and results removed doubts as to the safety of electrical vehicle 400V batteries in a deteriorated state; enabled the proposal of a modus operandi for fire brigade intervention; led to the modification of the architecture of the 400V battery casing and the vehicle itself to improve rescuer intervention; highlighted the need to standardize service plug location across the range of Renault electrical vehicles.

Thanks to this fruitful collaboration between Renault and French fire brigades, rescuers acquired knowledge and skills for intervention on Li Ion battery electrical vehicles.

## INTRODUCTION

When launching the Renault Electric Vehicles (EV) programs, the overall safety of these vehicles along their life cycle was a major concern for the company, as it already was for Internal Combustion Engine vehicle (ICE). The safety was integrated in the technical specifications by a careful selection of Lithium ion batteries safety concepts: electric architecture, service disconnect switch (SD/SW) integration, mechanical structure, " Battery Management System " ( BMS) protection strategy of the battery for a maximal safety level in all use cases. Many validation tests were led to guarantee the battery safety, including in abusive conditions such as: electrical abuse, thermal abuse, mechanical abuse and cell internal defect.

Renault's innovative way was to get involved, from the design of vehicles, first responders to study incindental situations of EV life cycle, such as road accidents and vehicles fires. Those sharing seemed particularly useful as it could raise relevant questions coming from fire brigades interventions habits and not yet identified by development teams.

## GOALS

The five actions areas identified with firefighters to guarantee their safety and the victims one in emergency interventions were the need of :

- Efficiently identifying the vehicle as electric.
- Getting the vehicle safe easily
- Keeping low the Li-Ion battery effect on extrication and extinguishing situations
- Creating common standards to help first responders decision (Emergency Response Guides, and Rescue Cards)
- Training them free of charge by our EV experts

## METHODS

The first step was to understand the difficulties of fire brigades during their interventions on crashed, burning, or immersed vehicles … During their intense exchanges, Renault and first responders drafted together the technical specifications of EV Emergency Response Guide to be sure to answer the real needs of the firefighters. To fill some chapters of this ERG and validate its EV safety level during rescuers future interventions, Renault conducted field testing together with fire brigades.

### EV Identification and safety

Fire brigades expressed their need to be able to distinguish the EV from an ICE in case of emergency intervention.

Renault took into account this necessity with standard distinctive visual elements in its EV; special Headlights, lack of exhaust pipe, logos Z.E. lack of petrol filling flap, underhood orange wires and connectors, specific elements on the dashboard

The BMS is in charge of managing the battery functional and dysfonctional safety , this is achieved by controlling both temperature and voltage and ensuring they remain in between the defined functional tresholds. Furthermore, aiming to guarantee the best safety level for people, Renault recommends beforehand in any intervention of extrication, to isolate the electric 400V circuit of the battery from the vehicle by disconnecting the SD/SW.

A 2 steps cut-off mechanism ensures the lack of electric arc during the operation of service plug disconnexion.

**First extrication tests on Electric Vehicles**

Renault was willing to verify before the selling of its two first EV models (Kangoo Z.E. and Fluence Z.E.) if the 400V battery and wires could affect usual extrications technics. A prototype of each EV model was thus given to French fire brigades so that they could check the possibility of keeping their usual cutting techniques .

They concluded that Renault EV wedging could be done the same way as ICE, including by applying rams directly on the battery casing. Weight distributions are different between EV and ICE, because of the lack of internal combustion engine and the presence of 300kgs batteries under the vehicle for Kangoo Z.E. and in the trunk for Fluence Z.E. As a matter of fact, if it lies on the roof after a crash, the EV is in balance (figure 1). It requires more wedging elements than for ICE which tilts forwards, because of its engine weight. Rescuers confirmed that Kangoo Z.E. floor had no risk of downward movement when positioned on the roof, in spite of the weight of the underfloor battery. They also showed that it was possible to extricate a victim through the Fluence Z.E. rear window when on the roof, using rams for example, in spite of the weight of the battery in the trunk (figure 1).

All the techniques of intervention used usually for extrication have been tested and rescuers concluded that none of their manoeuvre was forbidden by the presence of the battery or electric wires in Renault EV, because none is located in cutting areas. These results were used to fill in Renault EV ERGs and Rescue Cards .

*Figure 1 : a-Fluence Z.E. in balance on the roof ; b-poosible wedging on Kangoo Z.E. battery ; c- no downward movement of Kangoo Z.E. on the roof ; d-possible exit of victims from Fluence Z.E. on the roof despite battery located in the trunk.*

**Electric Vehicles first tests of fire in closed environment**

The aim of these tests was to answer the questions of fire brigades about EV (with Li-Ion batteries) behavior when involved in a fire. These first fire tests were organized by Renault and performed in the Centre National de Prevention et Protection (CNPP), in partnership with fire brigades.

They included bruning a Fluence Z.E. and a Kangoo Z.E. (with batteries at 100% charge level) in closed environment (16m x 19m x 2.9m) by placing them on an aluminum pan of 150 x 100 x16 cms filled with 150 l of alcohol, to ensure at least 15 mn to fire exposure.

After ignition started, each EV was left until total combustion (body and battery), without any external intervention. These tests led to the following conclusions: the kinetics of the fire of Fluence Z.E. and Kangoo Z.E. is similar to ICE fire. Without any extinguishing, the Li-Ion battery has a total combustion duration of 1 hour without any explosion. The EV close neighbooring temperature tops 900°C during the burning of the car and decreases to 350°C during the combustion of the battery. 5m away, the maximal temperature does not overtake 350°C (figure 2).

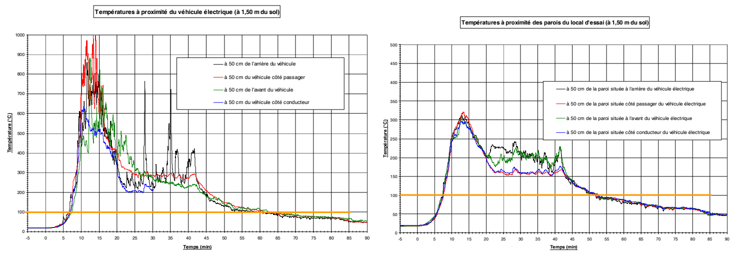


*Figure 2: EV close neighbooring temperature and at 5 meters distance*

Firefighters were able to conclude that this Renault EV fire behavior was similar to ICE fires they have experience with. Nevertheless, it was deemed necessary to perform comparative fire tests on EV and ICE to confirm these observations with quantified data.

**Comparative tests of EV and ICE fires in closed environment**

The purpose of this second test was to have comparative data between EV and ICE fire behaviour. These tests were performed by the "Institut National de l'Environnement Industriel et des Risques" (INERIS) on a conventional Fluence and a Fluence Z.E. . The only difference between these two cars is the presence of a Li-Ion battery instead of a diesel fuel tank. The Li-Ion battery of Fluence Z.E. was charged up to 100 % capacity and the diesel tank of the Fluence full (50L of fuel). The ignition was started into the passenger compartment from the driver seat with a gas burner.

As described in the first tests, there was no evidence of projections nor explosion resulting from the battery fire. The fire maximal thermal power and the total energy released are lower for the EV than for ICE: respectively 4.7MW against 6.1 MW, and 8 500 MJ against 10 000 MJ. The toxic effects during the combustion of the EV and the ICE were also compared.

Total quantities of CO2, CO, HCl, hydrocarbons, NO, NO2, HCN emitted during the combustion of EV are close or lower than those of the ICE (table 1).

**Table 1: Pollutants measurements [1]**

| Emitted gas (g) | ICE | EV |
|---|---|---|
| $CO_2$ | 722 637 | 618 487 |
| CO | 15 732 | 11 700 |
| HCl | 2 139 | 1 933 |
| NO | 740 | 770 |
| $NO_2$ | 410 | 349 |
| HCN | 178 | 148 |
| HF | 813 | 1472 |

Significant quantity of HF was emitted during combustion of both the EV and the ICE: a first peak of HF emission 14 min after the beginning of the test was observed in both cases. It results from the combustion of air conditioning fluid (figure 3).

A second wave of HF emission is observed in the case of the EV, linked to the presence of fluorinated salts in the Li-Ion battery. The associated kinetic is relatively slow and the instantaneous flow rates remain much lower than those from the the air conditioning liquid combustion. Moreover, it is interesting to notice that the overall amount of emitted HF from the battery is relativeley low compared to the potential content. Indeed, except the part linked to the A/C liquid combustion, assuming all the HF emitted from the vehicle comes from the battery, this is approximately 1050g of HF. Compared to about 5050g potentially contained into the battery, it is roughly only 20% of effective emission. This can be explained by the high affinity of HF for common metals present all over the vehicle frame (iron, steel, aluminum,...) thus it will react with apparent metallic surfaces and therefore will be less present in gaseous emissions. The total quantity of HF remains superior to the ICE, without preventing fire brigades from applying their usual intervention procedures [1]. During later intervention testing of Fluence Z.E. fire, a HF detector positionned on the first fireman shoulder never measured concentration exceeding the tolerated threshold in intervention.

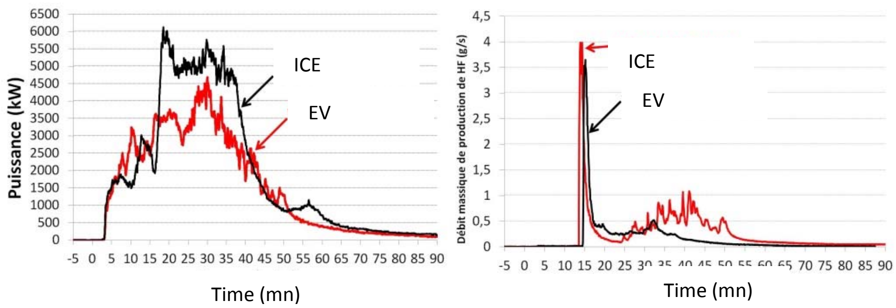


*Figure 3: comparison of released energy and HF emission during the EV and the ICE combustion.*

**First EV extinguishing tests by fire brigades.**

Prior to the selling of its two first EV models, Renault gave the fire brigades 2 Fluence Z.E. to perform outdoor fire and extinguishing tests. Firefighters wanted to reproduce the fire context of the most common vehicle fire situation : vandalism ignition, throwing a flammable object on the rear seats. As the objective was ensure the Li-Ion battery would catch fire, firefighters waited for 30 mn from the fire beginning and until launching the extinguishing intervention. At this moment, they could visually confirm the Li-Ion battery combustion, thanks to flames behind the vehicle. The firefighters extinguishing strategy was similar to ICE one: start from the front of the car, get rid of engine compartment fire, then move to the body and the peripherals (tires). Fire brigades *finally* focused on the Li-Ion battery extinguishing by spraying water on its casing for cooling . It was an ineffective attempt because the fire started again after every stop of water spraying, this until battery total ~~combustion~~ (~ 1h ). Following this extinguishing failing attempt, a reflection was led to define the best strategy to stop the Li-Ion battery fire.The second test of Fluence Z.E. fire and extinguishing was set up by flooding the battery from firefighters hose, directly into the battery cooling system. This second attempt appeared to be particularly effective because the complete and definitive extinguishing of the Li-Ion battery was achieved within 5min.

The following recommendation was thus proposed: the extinguishing of a Li-Ion battery is possible and effective only by filling it with common water in the aim to flood it.

As Kangoo Z.E. didn't provide direct access to the Li-Ion battery (whereas Fluence Z.E. did) , the question of how to flood the battery remained. Several tests of fire and extinguishing of Kangoo Z.E. were thus performed in partnership with fire brigades and the "Laboratoire Central de la Prefecture de Police" ( LCPP) to make sure that it was also possible to fill in the Li-Ion battery of this EV with water.

As the *main* objective was to be sure that the Kangoo ZE Li-Ion battery would *catch* fire during the test, firefighters filled the passenger compartment of wood pieces , and added some also on the ground underneath the battery. This set up was chosen to ensure a sufficient heat capacity to trigger the battery combustion. In every fire test, the Kangoo Z.E.battery, located under the vehicle, caught fire approximately half an hour after the beginning of vehicle fire. With the intense heat of the fire, it appeared that the Li-Ion battery aluminum casing melted in different points, allowing direct injection of water inside the battery, consequently the complete and definitive extinguishing was achieved in approximately 15 mn after the beginning of its combustion. [2]

The third Renault EV, ZOE, took experience from these fire tests results and integrated an innovative technical solution for allowing a fast and effective extinguishing of its Li-Ion battery: the "fireman access". It is a thermal fuse part based on plastic, located on the body of the vehicle, under the the rear passenger seat cushioning, which will melt because of the fire heat and therefore provide to firefighters a direct access to the vents of the Li-Ion battery (figure 4).

*Figure 4: Fireman Access on ZOE before, during and after the fire test.*

This worldwide innovation, allows efficient Li-Ion battery fire extinguishing within one minute, by flooding it with the fire nozzle. This shows a typical example of OEM taking in account the fire brigades needs. Since these tests took place, Renault integrated an additional requirement for this specific access dedicated to firefighters in the specifications of development of all its embedded Li-ion batteries. This “fireman access” presents a double interest: a direct and easy access for fire nozzle, and a direct view on the battery flames which makes easier the hole localisation , even for a first responder unaware of its existence. This improvement of rescuers intervention efficiency and safety was confirmed during others fire tests realized on ZOE in partnership with fire brigades and LCPP according to the same protocol as for Kangoo Z.E. (wood pieces inside the passenger compartment and under the vehicle). [2]. After usual extinguishing of the EV body, its Li-Ion battery was quickly and definitely extinguished by flooding it within one minute.

**Simulation test of fire coming from inside the Li-Ion battery.**

When it has been decided to add a “fireman access” in the passenger compartment of ZOE, the engineering team worried about a possible side effect in the highly improbable case of Li-Ion battery thermal runaway. Indeed, if a fire departure occurred inside the battery, would there be a life threatening risk (toxic gazs and smokes or flames) for the car passengers? To answer this difficult question and make sure that the “fireman access” would not decrease the safety level of the vehicle, a simulation test of fire coming from inside the Li-Ion battery was conducted, by overcharging a cell in the battery, considering this was the worst case possible of battery malfunction. This test was led once again in partnership with fire brigades and LCPP [ 3 ]. The heat increase of the overcharged cell was observed only after 1:30 hour of charging, and was associated with emission of smokes observed only outside of the vehicle (figure 6a). This phenomenon was observed during the heat propagation from cell to cell during 90 mn. During the same period, the heavily instrumented vehicle cabin (thermosensors, gas sensors & cameras) could not see any evidence of smoke nor flame presence inside the car. The LCPP and the fire brigades suggested to stop the test at this moment, concluding that if such a situation would occurred in the reality on EV with passengers blocked inside the car, rescuers would have enough time to extricate them .

After this test, the good behaviour of the “fireman access” *part* has been proved in spite of a skin temperature measured at 200°C (Figure 5 b and c).

*Figure 5 : a – external smokes during heat increase distribution in nearby cells of Li-Ion battery ; b &c - Fireman Access after heat increase distribution in nearby cells of Li-Ion battery.*

The conclusion of this test is that there is no increase of toxic risk or fire in the passenger compartment due to the presence of the fireman access.

**CONCLUSIONS**

All these tests contributed to improve knowledge on Renault EV safety when submitted to abuse situations such as road accidents and fire. Thanks to the intrinsic safety *level* of Li-Ion batteries on EV Renault and their BMS, as well

as to all the tests described in this paper, there is no particular risk found associated to EV for people (rescuers and car occupants). All the EV fire and extinguishing tests conducted in partenrship with fire brigades, that is 16 since 2011, guaranteeing a good reproducibility of the behavior of the Renault EV and their batteries (kinetics, intensity). Water was found an effective extinguishing agent for Renault EV battery Li-Ion. It is nevertheless necessary that the first responders are informed about the recommendations given by Renault. These knowledge, shared during the tests with some fire brigades experts, were thus *widely* distributed *to* fire brigades, by publishing on-line documents such as Emergency Response Guides (ERG) [ 4] [ 5 ] [ 6 ] ) and Rescue Cards [ 7 [ 8 ] [ 9 ].
At the same time, trainings on Renault EV intervention are given free of charge in French fire brigades *by* a Renault expert, also volunteer fireman. A partnership French Renault / fire brigade was also set up to propose these trainings in the fire brigades of other countries wishing to benefit from it.
These actions and the results obtained allowed to provide answers to the fire brigades questions on EV safety when involved in abuse situations. Operating procedures have been adjusted by fire brigade. Renault found how to modify the battery casing architecture and the vehicle itself to improve first reponders interventions, and integrated the necessity of homogenizing the location of its SD/SW in spite of the associated stresses *on* mechanical and electrical architecture.
These works have been made possible thanks to a close partnership between French fire brigades and Renault EV engineering teams. Each part has been able to deepen its knowledge, to make sure Renault EV safety level is at least equivalent to ICE one. Fire brigades were able to adapt their methods of intervention and Renault learned how to integrate into its specifications the particular needs of first responders.

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