Ultimate Technological Combination in Electronic Blasting, A Conclusive Contribution to Blasters’ Health & Safety

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Abstract

Electronic initiation devices appeared on the market more than 15 years ago and have definitely changed the rules of blasting. It becomes clear that this technology represents a powerful alternative to the traditional accessories.

Electronic Delay Detonators (EDD) have attained solutions that were difficult and even impossible to achieve with the previous technology, thanks to the accuracy, usually inferior to one millisecond, and flexibility of the programmability range offering thousands of timing possibilities.

Technological progress is long awaited to represent a step ahead compared with the last generation of products. In the case of electronic initiation, some limits nevertheless rapidly appeared, leading to the paradox of loosing operative and safety benefits, compared with the traditional technology it was supposed to outclass.

For all manufacturers, the time spent on the block to set the delay of the detonator is especially critical. More importantly, manufacturers now have to consider the inherent new safety parameters of electronic technology together with the traditional safety concerns.

Let us remember that injuries due to flyrock and lack of blast area security accounted for 61% of all blasting related injuries in surface US coal, metal, and non-metal mines during the period 1978-2003. Adding the injuries due to premature blast and misfires, it exceeds 82% for the same period [Bajpayee, Verakis & Lobb, 2005].

Delta Caps philosophy has always been to contribute to the blaster’s health and safety through technology, together with blasting result improvement. The combination of such unique features as centralized testing, programming and firing associated with wireless technology, reveals to what extent innovation can represent an opportunity for the blasting community to improve their overall safety and working conditions.

By combining the operative and safety benefits of fully centralized blasting with the proven, reliable and addictive wireless standard, six years ago the only electronic initiation device was created allowing the limits regarding flexibility, capability, reliability and, above all, safety to be broken.

After reviewing how unique this combination of advanced features is in the electronic detonators’ world, this paper presents the conclusive contribution to blasters’ health and safety it provides on a daily basis.
**Introduction**

Injuries due to flyrock and lack of blast area security accounted for 68% of all blasting related injuries in surface coal, metal, and non-metal mines during the period 1978 – 2001 [Verakis & Lobb, 2003]. Updating data gives quite comparable trends with close to 61% for the 1978-2003 period [Bajpayee, Verakis & Lobb, 2005]. By adding the injuries due to premature blast and misfires, it exceeds 82% for the 1978-2003 period.

Blasters’ physical integrity or lives lie just behind percentages, and then there is manufacturer responsibility and due diligence. From this comes our vision.

The key word of all the systems to be used in our industry is clearly safety. Then of course comes reliability, user-friendliness and efficiency, we always wonder how much they can contribute to safety. Maximum safety has to cover the blasters operating the system but also the whole human environment present on the site.

Considering electronic detonators as the latest generation in the long initiation devices history, what would an electronic initiation system be if it failed to integrate the ultimate compatible features which make the job safer and easier?

We trust also that relieving blasters’ pain, and not only when high altitude is involved, is a major contribution to workers’ health and safety.

By presenting how this philosophy takes the form of the electronic detonators we have now been selling for twelve years, this paper aims to present electronic initiation not only from an operative perspective but also as an opportunity to enhance blasters’ health and safety.

**Ultimate combination: centralized and wireless**

The volume blasted by electronic detonators is growing in a significant way, as well as the blasts’ mean size. Customer confidence in this technology is now a reality. Electronic detonator blasts are no longer small sized, well-framed and supervised experiments but now, for most manufacturers, they represent daily massive production blasts.

Together with feedback coming from the present users, the contribution to blasters’ health and safety is clearly one of the main criteria to continue switching from a traditional system to an advanced electronic initiation system.

Our company has always been on the cutting edge of technological progress for electronic initiation devices:

- 1994 : the first 100% centralized programming, testing and firing system was introduced and has never been outclassed to date.
- 2000 : the first wireless programming, testing and firing system was introduced, combining it with the existing centralized system.
- 2005 : based on six years usage and four years very positive track record in the field, we increased the wireless centralized blasting machine capability to reach the highest
expectations in terms of the number of detonators per blast, keeping health and safety as the main criteria for R&D and production policy.

After reviewing how unique this combination of advanced features is in the electronic detonators’ world, this paper presents the conclusive contribution to blasters’ health and safety it provides on a daily basis.

**What a centralized initiation system means**

**The technology**

Our company, since it was founded by Thierry Bernard in 1994, has proposed central programming avoiding the time consuming and non user-friendly hole by hole programming or ID assigning products. The key feature aims to send and receive the pertinent information from a single point to the whole sequence via a two-way communication protocol.

**The benefits**

**Nobody is exposed to risks when talking to detonators**

The occurrence of premature blasts, and their consequences in terms of flyrock, stated in the introduction of this paper, are explicit enough to justify the importance of this asset.

Electronic detonators represent a great improvement in terms of immunity against external environment stresses versus traditional technology. The resistance to shock and heat remain certainly comparable because of base charge similarity amongst fuse caps, non electric, electric and electronic. The real difference in favour of electronic detonator technology is all about electrostatic discharge (ESD) or/and electromagnetic impulse (EMI).

This very high level of resistance regarding ESD and EMI has been set as a basic requirement for electronic initiation safety due to the programming stage.

Shock and heat are typical non intentionally applied stresses. On the contrary, and on top of external ESD/EMI that may occur, programmability has introduced an intentional operation consisting of waking up an electronic circuit by internally circulating energy. Let us assume that all systems are equal regarding the level of immunity to ESD/EMI, but the exposure issue has to be solved, to be fully in accordance with the mines’ standard fault tree analysis management tools. Centralized programming guarantees no exposure for the blaster, whatever may happened inside the blast area.

**“What you design is what you get”**

**No risk of typing errors bringing flyrock and/or misfires**

“What you design is what you get” could be the motto for the second main asset of centralized systems. A quick sequence downloading with an integrity control focus getting rid of potential typing errors for timing: just imagine what 916 ms instead of 196 ms could
mean, especially in terms of safety. It might cause flyrock but we must also consider the misfire risk due to explosive desensitization (out of sequence).

**Double checking functionality**

A centralized system makes blasting design prior to all programming compulsory. That is the best possible way to make sure that hole numbers correspond to delay quantity, that itself corresponds to the planned timing for each hole in the sequence. Non matching data are immediately detected and located: that is another practical advantage of a 100% centralized initiation system.

**What's up with wireless technology ?**

**From a natural way to communicate to a proven technology**

Communication is by nature wireless. The only animal using a wire to communicate really is the mouse, today becoming extinction and replaced by... wireless ones. Tom-toms, smoke signals, carrier pigeons: wired communication has definitely been a short-lived human creation, a palliative for our technical first inability to imitate Mother Nature.

Indeed, the history of wireless technology goes far back in time. Already in 1843 Morse transferred the first message over a telegraph line in the USA.

Nowadays, no one pays attention to this anymore. Those applications are so common and in daily usage, that we do not even think that our safety or even our life depends on them [DOZOLME & BERNARD, 2005]. The Instrument Landing System (ILS) with the required top reliability of this wireless guidance system gives us the perfect example.

**The step back in time test**

Applying what we call the “step back test”, we easily conceptualise that coming back to wired technology would represent a real loss in terms of comfort and, in many cases, in terms of safety. There are many applications where this step back would even be impossible; let’s think of satellites, radar, etc.

Just think about all the remote technology applications present in your daily life. And just pass each of them through the “step back test”. What about going back to the wired version?

**Wireless technology in Blasting: why should blasting be an exception?**

To those who said that wireless technology in blasting is a brand new up-to-date technique, we now know how to answer. Wireless technology is not entering into the blasting world: the blasting world is just joining the undisputed and worldwide-recognised wireless standard. And why shouldn’t it?
Blasting deserves the best state-of-the-art technology. It would be nonsense for blasting not to enjoy the benefits offered by wireless technology. Electronic detonators have now proved their additional enhancements for fragmentation and vibration control [PARTOUCHE, 2002]. The latest generation of these initiation accessories is naturally awaited to bring such technology to the blasting community.

Then we can hardly believe that remote and wireless technology has taken so long to be applied to the blasting world. Why should blasting remain an exception and renounce the proven reliability and well-known benefits associated with this renowned technology.

Wireless technology allows blasters to initiate the blast from a perfectly safe distance, which is difficult and sometimes impossible to achieve with wired applications and/or traditional technologies (i.e. detonating cord).

Moreover, and for the first time, wireless technology gives the blaster the opportunity of keeping a DIRECT (and safe) eye on the field, and for him to be 100% sure that no one remains on the block when firing.

Substantial cost issues also have to be underlined even if they appear outside this paper’s focus. The net cost of a firing line (non electric or electric) saved on a daily basis has a significant impact on the yearly bottom line. For example, at Nchanga Open Pit Mine (Konkola Copper Mine) in Zambia, where electronic blasting has been used to protect the pit walls against vibration and slope failures, anything up to 1500m of shock is saved per blast. This is in addition to the safety and convenience achieved with the remote blasting.

What would an electronic initiation system be if it failed to integrate the ultimate compatible features which make the job safer and easier?

**Wireless technology in Blasting: following Deltadet© tracks**

Designed for maximum safety, this technology allows the Master Blaster to have a completely safe view of the blasting area, and avoids the so-called “fuse caps procedure”. With a distance of several kilometres/miles between the blasting spot and the block, the system has shown its reliability in all kinds of configurations and minerals.

For more than four years now, the system users are enjoying the wireless feature on a daily basis, successfully integrated into the production cycle. This technology has been first to introduce versatile wireless communication and to combine it with unchallenged centralised programming and firing. An encrypted communication between the relay box and the blasting machine, with the flexibility of a couple of kilometres range, offers a constant possibility of checking the communication status and quality, thanks to its specific software.

It has been successfully experimented in the biggest Chilean copper mines (Chuquicamata, Pelambres, Escondida) in the early 2000’s, both initiating non-electric and electronic detonators. Wireless technology was then extended on a production scale in South Africa, and the southern part of Africa, for 100% of our electronic detonator blasts now for more than four years and hundreds of thousands of detonators.
**The step-back test applied to Blasting**

“*I am not interested in any other electronic delay detonator system unless it has remote firing capabilities.*”

Stian BURDEN,
Head of Drill and Blast
Sishen Iron Mine, Kumba Resources

What really exceeded our expectations was our customers’ reaction to the remote programming and wireless blasting capabilities of the Deltadet System. Sishen is only one of the mines where the people, once accustomed to remote blasting, are no longer interested in anything else, for the following reasons:

- It is very safe due to the fact that the whole blasting area can be observed from the blasting point.

- It saves time and labour due to the fact that no blasting wire needs to be rolled out.

- It saves costs. When more than one block needs to be fired, they don’t have to be interconnected with detonating cord.

- It is very convenient and reliable

Let’s conclude that wireless in blasting is just as it has been for cell phones or TV remote control: furiously addictive.

**Break the limits with the unique centralized/wireless combination**

Technological progress is long-awaited to represent a step ahead compared with the last generation of products. In the case of electronic initiation, some limits nevertheless rapidly appeared, leading to the paradox of losing operative and safety benefits, compared with the traditional technology it was supposed to outclass.

A unique combination of advanced features combining remote programming and testing to remote blasting gives the real dimension of what electronic initiation is able to offer: safety & comfort in daily production blasting.

100% centralized associated with wireless blasting allows the limits to be broken regarding flexibility, capability, reliability and safety.
Breaking the flexibility limit

Limits you have in terms of sequence and timing are replaced by the greatest flexibility.

Breaking the capability limit

Centralized programming testing and firing of fifteen thousand detonators (15,000 detonators) is definitely opening new horizons for the blasting community. For more than 2000 non electric detonators in a blast, the overlap probabilities are getting technically difficult to prevent. Up until now, electronic detonator technology was unable to solve this problem due to their inherent lower capacity.

From the biggest open pit, we already have heavy demands for 3000 detonators in a blast, and, if possible the management of several thousand detonator blocks from a single point. Two configurations at that stage have been required :

- Blasting from a single point one thousand detonator blocks located in a single part of the pit but along different angles (dilution concern)
- Blasting from a single point one thousand detonator blocks located in different parts of the pit in a cost optimisation perspective (one clearance per week… or even per month!)

These new strategies coming from the very competitive mining industry are constantly challenging manufacturers for greater capability and flexibility while considering safety. The bottom line improvement coming from fewer clearances (suspending operation) turn thousand detonator blasts into a real site optimization objective for many mines throughout the world.

Centralization combined with wireless technology are making mine scheduling dreams become a reality with this electronic detonator capability, flexibility and safety.

Breaking the reliability limit

No more limits in terms of reliability between design and the field (what you design is what you get)

Breaking the safety limit

With up to five kilometres range (more than three miles) limits in terms of distance from the block to the blasting point dictated by the site configuration or blasting line rolls are less taken into account. Blasting point is then only determined by safety concerns.
II. Conclusive contribution to blasters’ health & safety

“For the past two decades, most explosives-related injuries and fatalities in surface mines occurred when workers were struck by rock, either because they were too close to the blast or rock was thrown much farther than expected.”

Verakis & Lobb, 2003

<table>
<thead>
<tr>
<th>Activity or cause</th>
<th>Fatal and non fatal injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of blast area security</td>
<td>51</td>
</tr>
<tr>
<td>Flyrock</td>
<td>26</td>
</tr>
<tr>
<td>Total</td>
<td>77</td>
</tr>
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Fig. 4 - Trends in flyrock and lack of blast area security injuries in US surface mining, 1978-98 - Source : Verakis & Lobb (2001)

1131 blasting-related injuries were reported by the mining industry during the period 1978-2003 [Verakis & Lobb, 2003 with updated data]. Blast area security accounted for 50.1% of these injuries followed by premature blast (11.4%), flyrock (10.8%), misfires (9.9%), and fumes (8.5%).

Fig. 5 – Distribution of blasting-related injuries in the US mining industry - Source : Bajpayee, Verakis & Lobb, 2005

Adding blast area security and flyrock causes to premature blast and misfires, makes the figure exceed 82% for the reported blasting-related injuries in the US mining industry within the 1978-2003 period.
Communicating with detonators from a safe place

Programmability raising a safety concern unknown with traditional accessories, i.e. communication with detonators. The first challenge facing the manufacturers has been to make this operation as safe as possible and to communicate about this for users to feel comfortable.

The 100% centralized programming, testing and firing philosophy was introduced by Delta Caps in 1994 as a direct answer to this concern and it is now considered as the safest standard. Avoiding personnel exposure is the best mitigating method to protect people from such potential hazard.

The idea is to avoid any communication with detonators while people are in the blasting area. As far as pyrotechnics and explosives are concerned such drastic measures and adapted technology are likely to be implemented by both manufacturers and users.

The determination of the bounds of the blast area is not an issue any more

Blast area & flyrock : what regulations and literature say

Federal and state regulatory agencies have imposed strict requirements related to flyrock and blast area security issues. 30 CFR Part 56.6000 defines ‘Blast Area’ as the area in which concussion (shock wave), flying material, or gases from an explosion may cause injury to persons. The CFR also states that the blast area shall be determined by considering the following factors:-

- The geology of the material to be blasted,
- The blast pattern,
- The burden, depth, diameter, and angle of the holes,
- The blasting experience of the mine personnel,
- Delay systems, powder factor, and pounds per delay,
- The type and amount of explosive material, and
- The type and amount of stemming.

30 CFR Part 77.1303 requires that ample warning shall be given before blasts are fired, and all persons shall be cleared and removed from the blast area unless suitable blasting shelters are provided to protect persons endangered by concussion or flyrock from blasting.

The Institute of Makers of Explosives (IME) has defined flyrock as the rock propelled beyond the blast area by the force of an explosion [IME, 1997]. Flyrock comes in different sizes and shapes, ranging in mass from a few ounces to several tons. Persson et al. [1994] referenced flyrock weighing approximately three tons thrown to a distance of 980 ft.

Three typical cases

Just three well known cases taken amongst dozens from literature:

- On July 5, 1990, a blaster standing on the top of a 200-ft highwall (~60m) about 505 ft (154m) from the blast site was fatally injured by flyrock [Daugherty & Frantz, 1990]. The highwall could not shield him from flyrock. The employee suffered a massive head injury
The flyrock originated from a toe blast. The toe round consisted of 23 holes ranging in depth from 3 to 5 ft (1-1.5m). The holes were loaded with 2-1/2-in diameter packaged explosive product. Explosive energy takes the path of least resistance and blasting small diameter angled toe holes requires special attention. The blaster failed to perceive that flyrock could strike him on the top of a highwall. This accident could have been prevented by using a proper blasting shelter or “matting” the holes.

- The Chief Inspector of Mines in Queensland, Australia, reported that a blaster was standing behind a steel hopper while video-taping a toe shot in a metalliferous quarry. Flyrock travelled about 246 ft (75m) and seriously injured the blaster. The blaster lost his right eye, his cheek bone was shattered, and his jaw was broken. This accident could have been prevented by using a proper blasting shelter.

- On February 1, 1992, a blaster was fatally injured in a surface coal mine [Boggs & Blevins, 1992]. The blaster positioned himself under a Ford 9000, 2-1/2-ton truck while firing the shot. Flyrock travelled 750 ft (~230m) and fatally injured the blaster. Taking shelter under a pickup truck, explosive truck, or other equipment is not adequate because flyrock can travel horizontally.

Wireless technology might be one of the powerful tools preventing such accidents.

**Mitigating techniques available**

Langefors and Kishlstrom [1963], Roth [1979], and Persson et al. [1994] have postulated concepts and developed theories to compute flyrock range. A blaster may use such concepts, in conjunction with past experience, to determine the size of a blast area.

Favreau & Favreau [2002], Preece & Chung [2001, 2002], Dare-Bryan, Wade & Randall [2001], and Katsabanis & Liu [1997] have used numerical simulation techniques to predict blast results by computing the interaction of rock and explosive. A blaster may be able to improve the design of a blast by using such simulation techniques.

To conclude, techniques to mitigate the flyrock risk include“proper blast design, driller-blaster communication, inspection prior to loading and firing the blast, removing employees from the blast area, controlling access to the blast area, and using a blasting shelter” [Bajpayee, Verakis, & Lobb, 2004]

We are now in a position to add an excellent mitigating technique on top of all those excellent tools developed throughout the years: wireless blasting.

**Wireless contribution: blasters’ safety**

Remote blasting that is possible thanks to wireless technology keeps the blaster safe at a location of his choice, without any constraint of wire length or bench configuration. The limit is defined by the five kilometre range allowed by the system. New standard??
This situation is directly linked to the difficult, time consuming and costly cable rolling. At Potgietersrust Platinum Limited (Anglo Platinum) and Rossing Uranium (Rio Tinto) mines, our electronic detonators have been used for fragmentation and pit wall stability. Both are deep open pit mines with narrow and steep benches, turning the blasting cable winding to a safe point of blasting, into a real key safety and production issue.

**Supervision of the blast area is critical**

**Three typical cases**

- On October 12, 1990, a visitor sustained severe injuries and a miner was fatally injured by flyrock in a surface silica flux mine [St. Laurent & Tanner, 1990]. The mining company used a blasting contractor for loading and firing the shots. The visitor and the miner were about 150 ft (~45m) from the edge of the blast. Upon firing the shot, the miner was fatally struck on the back of his head. This accident underscores the importance of identifying a proper blast distance and clearing the blast area.

- On April 25, 1994, a driller/loader was fatally injured by flyrock in a surface coal mine [MSHA, 1994]. The blaster notified the superintendent of an impending blast and cleared other employees from the pit area. The victim and another employee working under the direction of the blaster were about 236 ft (~72m) from the nearest blasthole. Upon firing the blast, the driller/loader was fatally injured by flyrock. This accident emphasizes the significance of being in a protected location or using a proper blasting shelter for employees whose presence is required in the blast area.

- On December 21, 1999, an equipment operator in a pickup truck was guarding an access road to the blast site [Yesko, Weber, & Lobb, 1999]. The pickup truck was about 800 ft (~245m) from the blast site. Flyrock entered the cab through the windshield and fatally struck the employee. The highwall face was about 50 ft high (~15m) and the depth of holes ranged between 49 and 54 ft (15-16.5m). The blast round consisted of 22 holes drilled on a 16- by 16-ft pattern (~5x5m). Some of the holes were angled up to 25º toward the highwall to compensate for irregularities in the highwall face. At least one of the holes blew out causing flyrock. This incident underscores the importance of being in a protected location.

**Wireless contribution: human environment safety**

At the same time, wireless technology offers blasters a unique feature with which no traditional technology can compare: the direct vision of the field, that means the possibility to directly and permanently check the field clearance.

Klipspruit Coal Mine (BHP-Billiton) is an open pit cast mine. The mine is located at the intersection of a national highway and another busy public road. EDD is used for environmental impact control – vibration, flyrock and noise issues. The traffic needs to be stopped on

![Figure 7: Wireless blast (2.7 km distance)](image-url)
both roads during blasting [Rorke & Tabethe, 2004]. Blasting is done from the waste dump where these roads and the blasting area can be observed.

**Improvement in blasters’ working conditions**

**Relieving pain: No more cable to unroll and to recover**

There is no universally accepted operational definition of fatigue. Certainly, it is more than simply being sleepy and its causes are more complex than merely the duration or physical nature of the work, although it involves these factors. It is now generally accepted that fatigue can be best understood by differentiating its source, its various dimensions, and its impact on performance [Heiler, Pickersgill, & Briggs, 2000].

Unfortunately, the above referenced research paper failed to take into account the pain factor of daily mining jobs, and how it affects the identified [Heiler, 2000] fatigue related problems, and accident/incident rate emerging at site level, in both coal and metalliferous mines:-

- Operators falling asleep and driving off haul roads;
- Loss of situational awareness common among truck drivers;
- Increased equipment damage towards the end of the shift;
- Lapses in concentration and increased errors especially at low circadian point in the early morning;
- Impairment of secondary task functions and reduced critical decision-making capacities;
- Poor performance where work is very repetitive, mundane and boring;
- Increased absenteeism as a result of excessive overtime;
- Loss of experienced personnel and increased stress among management;
- Uncontrolled contractor hours;
- Employees reporting sleep problems and disorders;
- Dissatisfaction balancing work and family responsibilities.

Unrolling and recovering blasting line is a painful heavy job especially when a long safety distance has to be respected, removing the blasting spot 700 meters or more away (around half a mile). The benefit is even greater as soon as altitude is involved, making every effort more painful. Chilean or Peruvian mines are, for example, frequently exploited between 3500 and 5000 meters (11500-16000 ft) above sea level.

Preventing such fatigue on a daily basis contributes to the whole site’s risk assessment that should not be underestimated.
Eliminating air blast and noise avoiding the detonating cord initiation method

At the Sadiola and Yatela gold mines in Mali (Anglo Gold), the standard practice is to use detonating cord as the lead-in line. EDD is used for pit wall stability and ore dilution. The detonating cord causes air blast and substantial noise, which is an environmental, technical and health problem.

Remote blasting not only eliminates the noise but also saves the mine the effort, time and cost of rolling out the detonating cord, as detailed above.

Conclusion

The blasting community’s suppliers have to remain focused on safety improvement while developing new technologies. The initiation accessories manufacturers are of course very involved.

New technology also has to focus on all the R&D trends that can prevent or relieve effort in the daily job, considering it as a contributing factor to incident/accident rates.

Together with accuracy and flexibility naturally provided by electronic initiation, Delta Caps has developed its technology to grant maximum safety via the centralized and wireless unique features.

Centralized technology, developed twelve years ago, offers the following contributions to health and safety:-

- No exposure when energy reaches the detonator’s circuit
- “What you design is what you get”
  - No risk of typing errors while programming, producing flyrock and/or misfires
  - Double checking functionality

Wireless technology, validated by more than 150 years of innumerable daily life applications, has been developed five years ago for blasting and has been used in daily production blasting for four years now and hundreds of thousands of detonators, offering such assets as :

- “What you see is what you blast”
  - Human environment safety
  - Blaster safety

- Improvement in blasters’ working conditions
  - Relieving pain
  - Eliminating air blast and noise
The combination of such unique features as centralized testing, programming and firing, associated with wireless technology, reveals to what extent innovation can represent an opportunity for the blasting community, to improve their overall safety and working conditions.

We trust that switching from a traditional initiation device to an advanced initiation technology gives customers more than a technical operative improvement, by maximising the enhancement of the health and safety standards of our industry.

Acknowledgements

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We take the opportunity to acknowledge the Institute of Makers of Explosives (I.M.E.) and especially its Electronic Detonator Sub-Committee, for developing and updating the “ALWAYS and NEVERS” list, and the good practices linked with the use of electronic initiation.

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