# Safety and Reliability for nuclear production

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**Abstract**
Nuclear production consists in producing electric energy from nuclear energy. If the basic idea is quite simple, the implementation gives complex socio-technical systems that imply strict rules and requirements to guaranty the safety of the industrial plants, and of course of the people working there or living around. This means that safety and reliability are definitely linked together, from the equipment standpoint as from the organiszational standpoint.

This paper explains how French nuclear industry operated by EFD, while not concerned by major accidents, is able to learn from the world-wide industrial feedback.

All what is presented here shows that "no accident on the nuclear fleet" does not mean "no re-questioning". On the contrary, it shows how the EDF company holds the "permanent re-questioning" as the meaning of "no accident on the nuclear fleet".

**Why such a subject and why such a title?**
The network Aquares49 wanted to gather around the table specialists of risky and complex socio-technical systems for them to present to physicians what had been set up in order to make work activities more reliable. In this aim, air line, merchant navy, nuclear industry and medicine specialists had to present their point of view concerning their own discipline. In this perspective, reliability was obviously a part of the presentation, but necessarily linked with safety: indeed, for French nuclear industry, reliability is sought for in order to guaranty the safety of the process and to prevent any diffusion of radioactive products in the environment.

Yet why speaking about nuclear safety? Because of nuclear production of course! Without any need and will to produce energy from nuclear power, the question of nuclear safety would not exist. This means that reliability and safety cannot be disconnected from production, and must be built taking into account the purpose of nuclear industry: producing energy.

These are the reasons why the three words, reliability, safety and production keep close to each other in this presentation title.

**Nuclear production of electricity: a simple and marvelous idea from the scientific standpoint**
Nuclear production consists in producing electric energy from nuclear energy. From the very simple idea which is the fission of atoms, warmness is obtained which is used to transform liquid (usually water) in gas under pressure for it to make a turbine turning. This turbine is coupled to an alternator which produces electricity.
From the scientific standpoint, this is a remarkable and marvelous technical and intellectual realization. This completion summons Nuclear Physics, Thermal Physics, Hydrodynamics, Hydraulics, Electrotechnics, Electricity, Materials Physics, Chemistry, Computer Sciences and Socio-psychological Science at least.

In the same approach, the conception of the industrial plant is based on a simple idea. The main loops are connected together to carry energy out of the core to the turbine connected to the alternator. The three loops are the primary loop with high pressure liquid water (155 bar, 304°C) in contact with the coil tubes, the secondary loop part liquid and part gas of water to make the turbine turning and thus the alternator, and a third loop as a cooling system of the second loop in order to reduce the vapor in liquid water to be re-injected inside the vapor generator. This third loop includes the tall aero-refrigerants making clouds of water over the nuclear plant. This basic conception description is presented on Fig. 1.

Unfortunately, the achievement of such a simple basic idea remains complex. When the primary loop is duplicated for a better efficiency, when are added safety and redundant loops to increase the safety level of the plant with differentiated pieces of equipment, and when you add to the Physics all the Chemistry in order to have

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a better protection of the metal apparatus, you obtain a complex technical system.

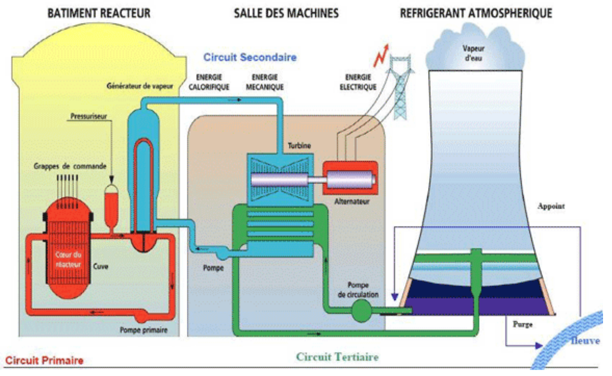


*Fig. 1: Simple drawing presenting the three loops of the Pressurized Water Reactors (PWR) of French conception: the primary loop in red, the secondary loop in blue, and the third loop in green.*

From the safety standpoint, basically three safety barriers are implemented to guaranty the confinement of the radioactive products and three loops to carry out the energy. For the Pressurized Water Reactors (PWR) of French conception, the three barriers are the fuel sealed metal tubes cladding, the heavy steel reactor vessel and the primary cooling loop, and the containment building.

And to make this complex technical system operate, you need women and men at work within an organization which is also complex. For example, a nuclear power plant like the one of Chinon (center France) with four reactors able to produce 900 MWe each, more than 1200 are needed permanently, and these people increase to the double during the maintenance periods which last several weeks per year for each reactor. It is clear that the complex technical system is transformed in a complex socio-technical system.

As we can see, from a basic simple idea of atoms fission, we obtain a huge industrial system operated by women and men. The questions of safety and reliability thus remain crucial: from the technical standpoints but also from the organizational and human standpoints. They are dealt with as soon as the plants conception, the operating period, and the dismantling.

**How to learn from a no accident operating feedback?**
Very few accidents have occurred for the world nuclear industry relatively to the amount of MWe produced and the number of operating years. Unfortunately, when such an accident happens, not only the operating staff is concerned by the consequences but also people leaving around the plant at a high level, and at a lower level, all the planet.

Nevertheless, conception of a nuclear plant is quite different from one country to another, even within the same country (like in Russia for example). It is the same for the safety policy of the country. This leads to the fact that the occurrence of a nuclear accident in a country is not easy to extrapolate to another. Thus, thinking that the 2011 Fukushima accident is an experience that must be used as an argument to stop everywhere with nuclear energy is a mistake: this would be equivalent to say that if one day a technical defect leads the Japanese Mitsubishi company to stop suddenly the use of their cars, this implies to stop the use of the French Renault cars. Of course, it would an aberration. This reasoning is valid for nuclear industry: the policy, conception, operating, environment, culture of French nuclear industry is so much different from the Japanese one that Fukushima accident cannot lead to the conclusion that French nuclear production of electricity must be stop.

Despite these important differences, the international feedback can be used by French nuclear industry to learn from accidental experiences. To illustrate this proposal, we shall restrain in this short presentation to the case of two items:

- The safety probabilistic studies.
- A multidimensional experience feedback (internal or external).

The safety probabilistic studies, or Probabilistic risk assessment (PRA), are a systematic and comprehensive methodology to evaluate risks associated with a complex engineered technological entity (such as an airliner or a nuclear power plant). Risk in a PRA is defined as a feasible detrimental outcome of an activity or action. In a PRA, risk is characterized by two quantities: the magnitude (severity) of the possible adverse consequence(s), and the likelihood (probability) of occurrence of each consequence.

For this aim, the fact that the French nuclear fleet is homogeneous is a real strength: a difficulty on one reactor gives at once an adjustment for all the others.

The multidimensional internal experience feedback is based on:

- Systematic event analysis for each nuclear power plant. Concerning this item, it must be noticed that EDF is the only nuclear operator in the world adding a level 0 (zero) on the International Nuclear Event Scale (graduated from 1 to 7) in order to declare and give to the national regulator all details even for safety event with no importance from the point of view of safety.

- Shared data banks.
- Statistical trend analysis.
- Injection of all the results produced by the above items into the safety probabilistic studies.
- Use of all the results produced by the above items to foster the experience feedback (Fauquet-Alekhine, 2012a).
- A permanent re-questioning of the organization robustness (for example, each plant re-questions some decision making process through an observatory for safety, radioprotection, environment, production).

Concerning the external aspect, the experience feedback analysis for the EDF company leans on:

- The feedback of important nuclear accidents.
- The accidentology, analyzing the important accident analysis, including all industries in every country.
- A permanent benchmarking and look-out.
- A permanent re-questioning of the socio-technical system.

We shall thereafter develop the external aspect of the multidimensional experience feedback.

***The feedback of important nuclear accidents***

The Three Miles Island accident (USA, 1979) led to optimize the Human-Machine Interface with a strong belief in the all-technology control. Focusing on this all-technology control has yet shown its limits and the Tchernobyl accident (Ukraine, 1986) has led to conclude that taking into account the HF aspects is thus quite important. This has notably pointed out that the Human contribution to the accident occurrence could be significant. It gave rise to the realization that the process safety could not be only or at least mainly based on technical automatic controls. The place of Human inside the process had to be reconsidered. This industrial catastrophe has shaked the world of risky industries and has led all decision-makers to seek work axis to reinforce the socio-technical systems and make them safer (Amalberti, 1996 et 2001; Reason, 1993 et 2008). For the French nuclear industry EDF, one of the main points has been to development a HF policy, with the creation of the job on each nuclear power plant: Human Factors Consultant. The HFC must help to take into account the HF dimension at work (Fauquet-Alekhine, 2012b).

More recently, the Fukushima accident has led to several analysis among which the own one of EDF. Within a few months, corrective actions have been identified and implemented. For example, despite the important differences between the Japanese and French socio-technical systems, the EDF analysis has pointed out that in case of a sudden problem with the same intensity than in Japan (whatever its nature), a French nuclear power plant could need a fast logistic rescue support. For this aim, the FARN has immediately been created. The FARN is “Force d’Action Rapide du Nucléaire” (Fast Task Force of the Nuclear) able to go beyond the conventional means in a short time (Fig. 2).

***Accidentology***

One team of the Research & Development laboratories of the company is devoted to this topic. Major accidents of any industrial fields in any countries are analyzed in order to understand the causes and to study the analytical method applied by the investigation board in charge of the inquiry.

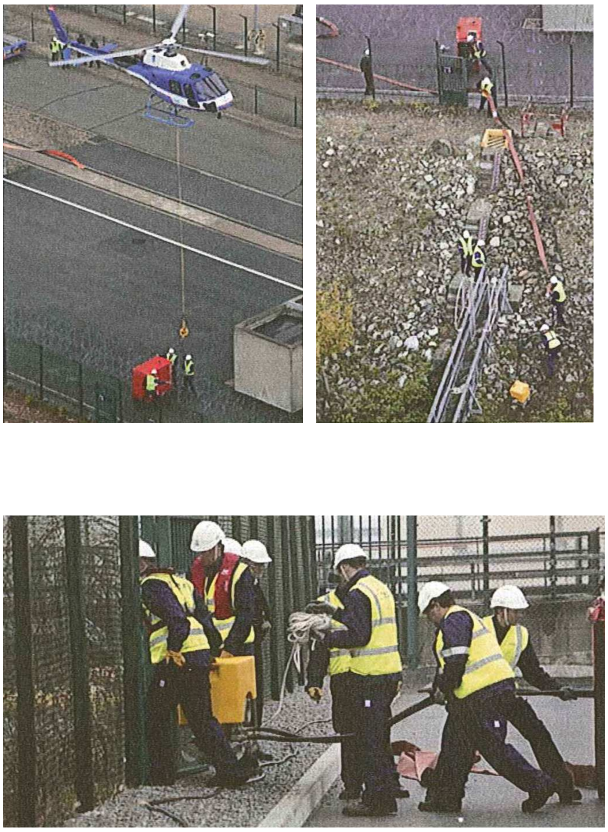

*Fig. 2 a, b, c. Pictures of the first exercise of the FARN took place in the French NPP of Cruas in October 2011.*

To give an idea of what can be done, we reproduce here the abstract of a communication concerning the subject and recently presented by researchers of this team to the society of French language ergonomy (Dien & Fucks, 2011):

*“Industrial risk management is a major challenge for companies. It is based in part on the benefits of learning from experience, lessons learned from the events. The*

*problem is therefore moved to the quality of the analyses of event. From an exemplary investigation of a rail accident, we will suggest that the ergonomic approach tools are essential for understanding the causes direct and immediate of the occurrence of an event but that the root causes apprehension convene from other social science concepts that are not yet integrated into the usual steps in ergonomics. In other words the ergonomic approach which is essential for the management of industrial hazards must also, in this area, incorporate the results of other approaches that are now less familiar."*

***The permanent benchmarking and look-out***

One of the recent productions of the benchmarking is the Human Performance Program implemented since 2006. A large benchmarking has been done (different countries, different industries) to identify especially: i) how can progress a safe industry by avoiding minor events? ii) what helps a worker to avoid minor events? The Human Performance Program is situated within the framework of the Human Factor policy of the company and involves organization, interveners and management of French nuclear power plants with the main aim to enforce nuclear safety. It consists of several items among which one concerns the workers in the field for who six Human Performance tools (HP tools) have been required for any intervention on the equipment. These HP tools are expected to soon be part of the professional practices of any workers of the French nuclear industry. They focus on the realization phase of interventions and make the link with preparation phase and feedback phase (Fig. 3).

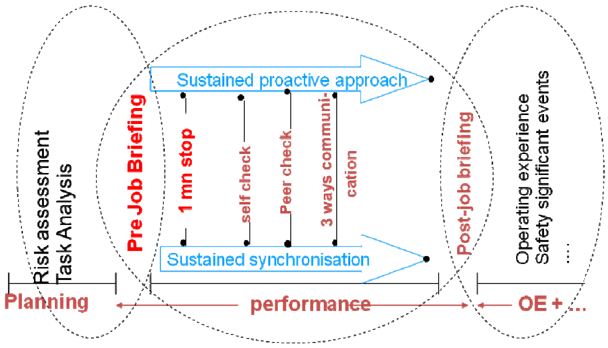


*Fig. 3: The six Human Performance tools expected to be part of professional practices, presented according to the three work activity phases: planning, performance, operating experience.*

The HP tools can be described as follows (Theurier, 2010):

- The Pre-job Briefing: located after the preparation of activity (including risk analysis) and its appropriation by the interveners, and just before the activity itself, the Pre-job Briefing is a specific phase of mental preparation and coordination for the interveners: sharing of perception, implementation of key risks in working memory, …
- The Take a Minute: located on the workplace and just before its start, it asked workers out of the urgency of action for analytical look at the work environment: am I on the right unit? the right track? the right equipment? do I have a risk of accident? … The "Take a Minute" is also used in case of interruptions or progressive drift of the situations outside the planned framework.
- Self-check: it permits one to avoid the usual global analogical way of reading. It asks analytic reading (read aloud and point the finger) of the identifier on the procedure and its corresponding tag on the equipment before implementation of an action.
- Peer-check: it asks, in addition to the self-check, another person to verify the coherence between the intention announced and the draft of the action to complete before it starts. It helps strengthen vigilance.
- The Debriefing: it definitely finished an activity by expressing difficulty and facility encountered in the action and the "innovative" means in place to achieve the result. It is a point of engagement inside a loop of progress for future interventions.
- Reassured communication or 3-way communication: it allows to ensure that information has reached the consciousness of the intervener while he was focused on his/her activity. The addressee must repeat the information received and the addresser must confirm the accuracy of the repetition.

Note that none of these practices (excluding the content of the debriefing) is expected to be written. This avoids any "administrative" drift.

Quantifying the results induced by such actions is difficult because they are always part of an action plan. What can be rated is the result of all of these joint actions. To give just two indicators, since 2006, i) the number of reactor automatic scram for French nuclear power plants has been reduced by more than 20%, which is considerable, ii) the number of events involving a punctual error has progressively and constantly diminished as illustrated by the graph on Fig. 4.

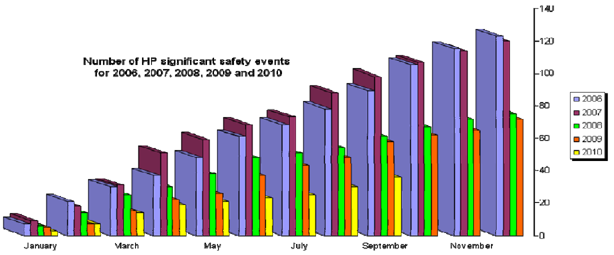


*Fig. 4: Variation of the number of events involving a punctual error of workers since 2006.*

Another recent production of the benchmarking is an organization of the experience feedback and its integration by the PAC (Fauquet-Alekhine, 2012a): « le Programme d'Action Corrective », inspired by the American CAP (Corrective Action Program). The PAC is based on a frequency of analysis of the input findings in a computer database, and a closure findings-analysis-actions-results-findings. Identification of the experience feedback and the material of which it is made up are done via the findings every day. The consolidation of data entering is made the day after to verify the characterization of the findings and to ensure homogeneity of these characterizations. This point is fundamental because if there is heterogeneity at this level, trend analysis and statistical analysis are generally impossible. Then, the findings are prioritized, posted weekly and kept in check weekly and monthly. The aim is to appreciate whether the findings are archived for memory without action, or for simple action, or for specific analysis. The whole gives rise to trend analysis.

Quantifying the results of such action is not yet possible because of the very recent character of this action.

***The permanent re-questioning of the socio-technical system***

This state of mind and the consecutive organization is fundamental to maintain the socio-technical system in a permanent progress loop. All domains are concerned within the company and thus examples are numerous. We shall take just one example linked with what was exposed above following the Tchernobyl accident. The consecutive Human Factors policy has been re-questioned several times. In this framework, the Human Factors Consultant position has been re-defined. If we have a look at the history of the job, since the beginning, six steps at least can be identified:

- 1993: the Human Factors Consultant (HFC) position has been created within the company.
- 2000: the recruitment for this job has been adjusted according to the first feedback years.
- 2002: the profession has been included within a specific management of the company jobs and the profession guidelines have been published.
- 2008: jointly with industrial partners, a professional master has been created in order to offer newcomers in the job an academic background adapted to the need.
- 2010: because of economic context changing and staff renewal, and thus human factors context changing in the company, the job profile has been revisited thanks to all the HFC of the nuclear fleet and their contribution has led to an adjusted re-writing of profession guidelines.

**Conclusion**

All what is presented here shows that "no accident on the nuclear fleet" does not mean "no re-questioning". On the contrary, it shows how the EDF company holds the "permanent re-questioning" as the meaning of "no accident on the nuclear fleet".

Especially, referring to Bird's pyramid (1966) reproduced on Fig. 5 obtained through a survey of 1,700,000 accidents and based on Heinrich's work (1931), the systematic event analysis policy concerns all levels of the pyramid: the upper part is investigated through foreign events, and the bottom part is analyzed according to the internal experience feedback improved and reinforced periodically according to the re-questioning of the socio-technical system and to the benchmarks and permanent look-out. In agreement with Bird's findings, the policy consists to correctly improve accident prevention, which implies to properly identify weaknesses in the organizational system that have potential for loss.


*Fig. 5: The Bird's pyramid (1966) showing that there exists 1 major accident for 600 minor events.*

This contributes to the guaranty of a safe operating of the French nuclear reactor fleet. What must be kept in mind is that the zero-failure does not exist as it is an utopia, but we can seek the zero-consequences.

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