Safety Improvements – objectives and methods

Pieter De Gelder, Martial Jorel**, Heinz Liemersdorf****

*AVN, Walcourstraat 148, B-1070 Brussels, Belgium
**IRSN, BP 17, F-92262 Fontenay-aux-Roses Cedex, France
***GRS, Schwertnergasse 1, D-50667 Köln, Germany

Abstract:
For achieving and maintaining a high level of safety of nuclear installations, safety improvements are playing a major role.
This paper focuses on objectives and methods of safety improvements. The major input sources to improvements – operational experience feedback, safety studies and Research and Development - are dealt with by describing their role, processes and methods used, and by illustrating examples.
Also some future challenges identified by the 3 co-authoring TSOs are given.
Finally, throughout the paper, the importance of future TSO-networking is illustrated.

1 INTRODUCTION

Since long time, safety has been a major point of attention in different types of industries. It remains important and its importance can only grow in future. This is certainly valid also for the nuclear industry.

To achieve safety, a good design concept is needed from the very beginning of the lifetime of an installation. However, this is not sufficient. There are indeed many inputs during the lifetime of a nuclear installation showing that safety can only be maintained through a continuous effort and the past has made clear that safety improvements are an essential contributor to this effort.

This paper will give an overview, from the viewpoint of 3 European Technical Safety Organisations (TSOs), on the objectives and methods applied to safety improvements. Different input processes will be described, based in particular on the wide experiences available within the 3 TSOs concerning the safety of nuclear power plants.

Although it is the conviction of the TSOs that indeed a high level of safety has been achieved for nuclear installations, the paper will illustrate why also in future a continuous effort to improve safety will be indispensable.

2 SAFETY IMPROVEMENTS FROM OPERATING EXPERIENCE

2.1 Input and triggers

It will be clear that operating experience is a first but very important input source and trigger for analysing and defining safety improvements.

Within this input source a wide scope of events are contributing. There have of course been some major events like the Three Mile Island and Tchernobyl accidents that had a major impact on defining safety improvements, as well for the worldwide NPP park as for some reactor types in particular.

However, lessons learned from incidents play an important role as well in improving safety. The corresponding analyses, including “what if” analyses, focus mainly on how to avoid recurrence of these incidents and on how to obtain a better defence for mitigation in case they would reoccur.

Finally, all kinds of observations, included events not even categorised as an incident, can contribute to safety improvement when applying a proactive safety culture.

Nevertheless, it is worth emphasizing that the possibility to take full advantage from the plant operating experience is strongly conditioned by the free availability of operational feedback data from utilities. From that viewpoint, the deregulation of the electricity market could represent a potential danger because of the increased level of confidentiality, which could be imposed by utilities on their available data.

2.2 Process and methods

The importance of operating experience for defining safety improvements being evident, the whole activity is since a long time dealt with within a specific process. Most organisations involved in safety of nuclear installations - be it licensee, safety authority or TSO – are managing an operating experience feedback process. Often, distinction is therein made between “internal“ experience feedback, dealing with events occurring at the “own” installations, and “external” experience feedback, covering events in other installations.

This operating feedback process is also a good example of a domain that has benefited enormously from international collaboration. International organisations like IAEA, OECD/NEA [1] and, to a lesser extent the EC, provide several fora and working groups (see for instance [2]) dealing with this matter. In particular, the Incident Reporting System [1], jointly operated by IAEA and OECD/NEA, has a longstanding contribution in this respect. From the nuclear power plant operator’s side, the efforts undertaken by WANO [3] can be mentioned.

Originally events were mainly analysed in a deterministic way. The event was analysed in detail, contributing factors were identified up to the identification of root causes and, where appropriate, corrective measures were analysed and implemented. Later on, when probabilistic safety analysis became more developed, the probabilistic approach was also used to analyse events [4]. The probabilistic approach for event analysis, which has been widely adopted in many countries, permits a more precise appreciation of the incurred risk, that, in turn, enables appreciating the urgency of the corrective actions to be adopted and scheduling them accordingly. It is one example where the deterministic and probabilistic approaches are now used in many countries in a complementary way for improving safety.

2.3 Examples

Many examples of safety improvements stemming from operational experience feedback could be given. They cover as well the aspect of installation safety (design, construction, etc.) as the aspect of operational safety (operational practices, procedures for accident or incident management, training, safety culture).

In Europe for instance, in the early eighties, lessons learned from the Three Mile Island accident had a major impact on both installation and operational safety, while later the Tchernobyl accident was for most European plants (due to design differences) more important for the safety culture aspects involved in the event. Both events also lead to a growing attention for beyond design basis and severe accidents. This has meanwhile resulted in a wide range of safety improvements, dealing with situations not considered at the original design. For instance, in France, a large investigation on the initiating causes and scenarios of the reactivity driven accidents was launched immediately after the Tchernobyl accident. Studies performed on the so-called heterogeneous dilution transients, which include probabilistic aspects, led (in France and in other countries) to the definition and implementation of actions, quoted as “dilution prevention actions” aimed at preventing the introduction in the core of un-borated or cold water as a consequence of an uncontrolled primary pump restart. For future installations, beyond design basis events and severe accidents (now often called design extension conditions) receive much more attention from the early design stage on.

Even for conditions considered at the design, operating experience can highlight the need for improvements. The event that occurred at the Barseback plant in 1992 where problems were brought forward concerning sump recirculation have lead to important modifications in the past and further evaluations are still ongoing [5, 6]. The modifications being implemented for this issue are an illustration of the fact that some modifications are needed to restore the safety level originally intended rather than to improve safety (as also discussed in [7]). In France, Germany and Belgium (as in other countries) important efforts are being devoted presently for resolving this issue. Complex phenomena concerning release of insulation (and other) material, transport of the material within the containment and in the sump water, and pressure loss at the sump strainers have to be dealt with. For all of these phenomena, chemical effects render the evaluation even more difficult.

Numerous other examples of operating feedback can be given, as well on design and construction aspects (1998 Civaux incident with a leak in the residual heat removal system; 1999 Cattenom cladding failure incident; German experience on corrosion leading to exchange of main coolant piping of BWR plants; German experience on cracks in bi-metallic welding, …), on operational aspects (2001 Dampierre incident related to fuel reloading; 1999 Nogent incident with incorrect adjustments of electrical protections; improvement for German BWR of reactor protection signals in case of neutron flux oscillations, 2001 Brunsbüttel event leading to countermeasures to avoid radiolysis gas accumulation, …) and even on site related aspects (1999 Blayais incident on site flooding; …).

3 SAFETY IMPROVEMENTS FROM SAFETY STUDIES

3.1 Input and triggers

From the early beginning of nuclear safety, the importance of safety studies has been acknowledged. Even for the first NPPs that have been built in Europe, a comprehensive Safety Analysis Report (SAR) formed the basis for the licensing. Besides a descriptive part, the SAR highlights all safety studies that have been performed to demonstrate that the plant is sufficiently safe.

Originally, most of these studies were based on the deterministic approach. A set of regulations, guides, norms and acceptance criteria were defined. If this set was followed and if the acceptance criteria were met, then the plant was judged sufficiently safe. Later on, this approach was complemented with the so-called probabilistic approach, materialised via the Probabilistic Safety Analysis (PSA) and now performed for almost all plants. The introduction of this probabilistic approach has led to new insights and many safety improvements. It was realised that some accident initiators were more important than thought originally (for instance, small break LOCA compared to large break LOCA; steam generator tube rupture: initiators during low power and shutdown states). Since then, both approaches are used in a complementary way.

Not accounting for the learning from the operating experience, which, in general, originates a large amount of studies, several studies have been launched to account for (based on examples from France):

- new requests with respect to the original design (e.g. resistance of the equipment hatch in case of major accident),
- availability of new materials (e.g. cooling pipes in composite materials),
- new operating conditions of the plants (e.g., advanced fuel strategies and loadings), which implies a re-evaluation of the operating margins with new tools and methodologies (computation chains)
- changes of assumptions and conditions in the safety report (e.g. an increased power in fuel storage and cooling pools),
- an improvement of the safety demonstration on either an important or highly sensitive issue (e.g. coupled thermal-hydraulics mechanical calculations of the reactor vessel cold chock in case of a safety injection after a small break of the primary circuit).

3.2 Process and methods

Periodic safety review is a typical process that has a major contribution on safety improvements through safety studies. In all European countries, periodic safety review (PSR) is nowadays common practice. Typically every ten years a comprehensive overview of the plant's safety status is realised. Within this overview, new or revised safety studies play an important role.

At the onset of a PSR, a list of subjects to be treated is often elaborated between the Licensee and the regulatory organisations. For older plants, some analyses are performed for the first time (because at the time of licensing those analyses were not required); other analyses need sometimes updating because of new insights on modelling aspects or because new phenomena, identified through progress in science and knowledge, are taken into account. It has to be stressed that also the improvement in analysis tools (more sophisticated computer codes) and methods contribute to improving safety.

An important characteristic of the PSR is that safety improvements can be decided in an integrated effort (sometimes leading to global solutions) rather than on a case by case basis.

3.3 Examples

The most striking examples of safety improvements realised in the framework of a PSR are related to older NPPs. Sometimes, those plants have been analysed with respect to initiators that were not at all considered at the design stage, such as external events (earthquake, high winds, ...) and man-made hazards (large fires, explosion in industrial facilities, ...). By taking measures - to the extent possible - for protecting the plants against such hazards, their safety was improved. Also physical separation with respect to internal hazards such as flooding of internal fire was often improved.

Based on PSA insights, several plant improvements have been implemented in all countries. At one hand, from level 1 PSA, many conclusions were drawn that allowed to improve accident prevention (lowering the core damage frequency) by hardware modifications (e.g. up to adding an additional residual heat removal system for a specific plant), by focusing with another approach on human performance (leading to improving and sometimes automation of shutdown and emergency procedures), by increasing safety at non-power and shutdown condition (especially for mid-loop operation), by highlighting the potential importance of common mode failures (e.g. in Germany leading to further diversification of (sub)-components of valves), etc. At the other hand level 2 PSA contributed to improve accident mitigation (reducing the potential and magnitude of environmental releases), amongst others by backfitting plants for a better coverage of the hydrogen explosion threat and even for some plants by providing means for ex-vessel coolability of corium in case of severe accident.

Another example concerns the safety of the fuel storage cooling pool that has been completely re-examined for the French plants. The plant licensee (EdF) performed a preliminary safety study on fast draining transients. The analysis was checked by IRSN, who detected a potentiality for large and fast radioactive release and stated for the need of a significant improvement as regards the defence in depth (modification of equipments and/ or implementation of procedures).

4 SAFETY IMPROVEMENTS FROM R&D AND TECHNOLOGY DEVELOPMENTS

4.1 Input and triggers

A last input towards safety improvements, although an important one, stems from Research and Development (R&D) and technological developments.

When safety issues are brought into light, sometimes considerable R&D efforts are needed to clarify the issue further and to identify what can be adequate measures in view of safety improvements.

Also new technological developments have brought their contribution towards safety improvement, often in combination with R&D. Sometimes new technologies have very promising characteristics, but their implementation has to be performed with care in order not to introduce hidden drawbacks.

Also the tendency to use more and more best estimate analysis with quantification of uncertainties (for instance for plant changes involving increase of thermal power) can only be implemented through R&D activities in codes and methods.

Difficult and strategically important topics, such as reactor vessel and confinement resistance, non destructive-controls, ageing, are relevant to R&D programs with the aim to take full advantage from the up-to-date learning from operating experience, experimental program results and progress in computation features.

The significant changes both in materials and in reactor operating modes threaten the key-parameters adopted in the safety report. For example, introduction of new reactor materials and adoption of advanced operating parameters (e.g., the fuel burn-up), as well as the connected experimental results (fuel clad swelling, fuel clad quench) engender new R&D actions.

In addition R&D efforts can sometimes be triggered by economical interests (e.g. for optimising fuel loading strategies).

4.2 Process and methods

For doing sophisticated research in specific fields, important efforts are needed for manpower and sometimes for infrastructure (test installations). In consequence, the field of R&D is nowadays more and more conducted in different international frameworks. OECD/NEA [8, 9] and EU [10] have important R&D programs related to safety of nuclear installations.

In this field the TSOs play often an important role at the regulatory side. Sometimes TSOs participate intensively in R&D work itself; in other cases their scientific competence allows to collect and evaluate R&D results, with as objective to provide a well funded basis for further decision making by the safety authorities.

4.3 Examples

As mentioned before, considerations concerning severe accidents and their mitigation have received increased attention with time. Before the phenomena were well understood and in view of defining feasible and adequate severe accident management measures, a lot of R&D in the field has been done and is still pursued. Especially in this field, international efforts are undertaken [11, 12]. Theoretical and experimental findings of R&D have allowed to identify and to implement emergency measures and procedures to cope with some severe accident conditions.

Several years ago, nuclear industry was challenged by the introduction of a new technology in I&C of the plants. For new plants, but also for upgrading older plants, more and more use was made of systems with integrated safety critical software. This raised new issues for system designers, licensees and regulators, in order to ensure that this new technology was implemented and licensed with full respect of all safety aspects [13, 14].

An important outcome of R&D is also the improvement in safety analysis tools. Experience has learned that for complicated issues a combination of advance codes (e.g. CFX, multiple phases) might be needed, verified by generic experiments and additional experiments to improve the correct modelling for the phenomena discussed and to identify the data input (e.g. plant specific). Since long time, IRSN and GRS are amongst the leading organisations in code development and improvement, which is highlighted in several other papers during this EUROSAFE Forum.

5 MANAGEMENT OF SAFETY IMPROVEMENT PROCESS

First of all it will be clear that the 3 “triggers” for safety improvements mentioned above are strongly linked. Findings from operational feedback will sometimes need additional safety analyses for defining adequate measures for improvements. Additional safety analyses, sometimes covering new aspects, may require additional R&D, and so on. Therefore, the management of the safety improvement process is very important in ensuring the safety of nuclear installations. A major cornerstone for integrating all these aspects is without doubt the concept of the Periodic Safety Reviews. They provide indeed a framework in which global solutions might be developed instead of solving specific problems separately.

Also the development and continuous improvement of rules and regulations is of course a major factor in managing safety improvements. Besides national regulations, also important efforts have been made to improve international safety standards (as for instance those developed by IAEA [15]. Also here there is a continuous symbiosis; new safety insights and improved operational practices are gradually introduced in rules and regulations, which then serve a new “standard” to be complied with by all installations.

A more recent effort in improving safety of nuclear installations are some international projects on harmonisation. In particular the Reactor Harmonisation Working Group operating within the WENRA framework is presently putting an important effort in defining reference levels on different issues of nuclear power plant safety and in benchmarking the national status on legal requirements and implementation with respect to these reference levels. A similar harmonisation effort is being performed by the WENRA Working Group on Waste and Decommissioning. It is expected that the action plans to be defined in the near future will further contribute to improve nuclear safety of installations in all participating countries.

The importance of international collaboration to improve safety is clear from the above. Many TSOs are contributing actively to this development and in particular the co-authoring organisations of this paper - IRSN, GRS and AVN – are fully aware of their responsibility in this process. This leads to a situation of closer networking amongst those organisations. A concrete example is the recent publication of a common Safety Assessment Guide [16], outlining fundamental principles to be applied in the evaluation of safety assessments.

6 FUTURE CHALLENGES ON SAFETY IMPROVEMENTS

Although continuous safety improvements have been achieved in the past, the co-authoring TSOs still see several challenges to be tackled in future. Some of them are shortly described hereafter.

The treatment of non-conformities with respect to the original design, discovered in the framework of the periodic safety review, may give rise to specific practical problems. Even if the specific actions engendered by those discoveries are formally requested, nevertheless the planning of interventions and the definition of procedures were sometimes the source of very important delays. It should be emphasized that the effort made to increase the plant safety should not hide the need for a continuous and accurate watch on the plant status, both from the point of view of the replacement of equipments and the actions and interventions needed to keep the plant in operating conditions responding to its safety report.

Since long time high efforts have been devoted to improve the nuclear installation safety with particular attention on design and operational practices and conditions. In the past, amongst others based on insight from operational feedback, the importance of the human factor became clearer. Probabilistic safety assessment, in which operator performance is considered to the extent possible, brought already an additional tool to evaluate the importance of this factor for nuclear safety. The impact of some aspects however, in particular organisational aspects and safety culture attitude, remain very difficult to quantify in PSA. Given also that many licensees are undergoing important reorganisations due to merging etc., organisations become more complex. A clear delineation of responsibilities within a complex organisation is an important point of attention. Also the integration of the human factor in implementing safety improvements (design, operation, maintenance, testing, ...) needs continuous attention. Therefore important efforts will have to be devoted to these aspects in future and the co-authoring TSOs hope to contribute to this with their knowledge and expertise.

Another aspect is the judgement on the further need for safety improvements. Once a high level of safety is achieved, the question can be raised how to decide on further safety improvements. It can be foreseen that Safety Authorities and their TSOs will be confronted more with questions on the balance of safety benefits obtained and corresponding costs.

In this paper, many aspects and examples of safety improvements have been given related to nuclear power plants. This is easily explained by the fact that their risk is potentially high if safety is not adequately managed. However, by improving their safety continuously, the question has to be raised whether at a given level other types of installations, having intrinsically a lower risk profile, should not get growing attention. For instance, within the NPPs themselves, most attention has certainly gone in the past to reactor safety, but maybe in future other aspects such as spent fuel storage, temporary waste treatment or fuel handling activities should get more attention. Also other installations of the nuclear fuel cycle, in which human interventions are frequent and less "standardised" may warrant further efforts for safety improvements.

As a last example, we see a challenge in balancing adequately the different levels of defence in the so well known (and successfully applied) defence–in-depth approach. Since installation safety and operational practices have been subject of many improvements, we should also maintain efforts towards high performance and improvement where possible of the last level of defence, being emergency management. It is well known that also in this field international collaboration has increased considerably over the past, with an important role being played by international organisations such as IAEA, OECD/NEA and EU.

Based on these examples of future challenges, and knowing that there are certainly even more, the co-authoring TSOs are fully aware that adequate coverage of these challenges will need strong collaboration. Sharing of knowledge and experience will be a cornerstone in achieving the objectives and that is way IRSN, GRS and AVN also undertook recently some exchanges of information on Knowledge Management and are trying to define further R&D work in that area. With this the importance of TSO-networking is again highlighted.

7 CONCLUSIONS

The 3 co-authoring TSOs – IRSN, GRS, and AVN – are strongly convinced that through continuous safety improvements a high level of safety has been achieved.

For their own, they hope to be able to contribute further to nuclear safety through evaluation of international operational feedback, through further improvement of safety analysis methods and tools, which will certainly require a continuous effort in Research and Development.

Achieving this "alone" would be wishful thinking; further joining efforts by TSO-networking is judged to be essential for achieving our objectives.

8 REFERENCES

[1] Nuclear Power Plant Operating Experiences from the IAEA/NEA Incident Reporting System 1999-2002 (Jointly prepared by IAEA and OECD/NEA; 2003)

[2] OECD/NEA Committee on the Safety of Nuclear Installations (CSNI) - Working Group on Operating Experience (WGOE); see http://www.nea.fr/html/nsd/csni/wgoe
[3] WANO review “safety f1rst” (October 2005); see http://www.wano.org.uk/
[4] „PSA-based Event Analysis“; OECD/NEA/CSNI Technical Opinion Paper No. 6; OECD/NEA 2004.
[5] “Knowledge Base for Strainer Clogging - Modifications performed in different countries since 1992”; Report OECD NEA/CSNI/R(2002)6
[6] “Summary and Conclusions of the OECD/NRC Workshop on Debris Impact on Emergency Coolant Recirculation”; Albuquerque, NM, USA, 26-27 February 2004; Report OECD NEA/CSNI/R(2004)2
[7] “Improving Versus Maintaining Nuclear Safety”; OECD/NEA (2002)
[8] “Collective Statement Concerning Nuclear Safety Research – Capabilities and Expertise in Support of efficient and Effective Regulation of Nuclear Power Plants“, OECD/NEA 2004.
[9] „Regulator and Industry Co-operation on Nuclear Safety Research“; OECD/NEA 2003
[10] 6th Framework Programme of the European Union; FISA conferences related to previous Framework Programs
[11] NEA Annual Report 2004; OECD/NEA
[12] Network of Excellence for a Sustainable Integration of European Research on Severe Accident Phenomenology; SARNet Network of Excellence; EU 6th Framework Programme
[13] “Software for Computer Based Systems Important to Safety in Nuclear Power Plants”; IAEA Safety Guide NS-G-1.1 (IAEA; 2000)
[14] “Common position of European nuclear regulators for the licensing of safety critical software for nuclear reactors”; European Commission’s Advisory Experts Group Nuclear Regulators Working Group; DG Environment (May 2000)
[15] IAEA Safety Standards; see http://www-ns.iaea.org/standards/
[16] Safety Assessment Guide; IRSN-GRS-AVN; document available on website of the 3 organisations