Recent Results and Trends from Generic Evaluation of German Nuclear Power Plant Operating Experience

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Abstract

Operating experience feedback is an important tool to maintain and improve nuclear safety. Usually, this feedback process is limited to nuclear facilities. In August 2003 the official report on the Columbia space shuttle accident became available. It provides interesting insights on how the accident could happen. A key area contributing to the accident are deficiencies in NASA´s operating experience feedback process. On principle, there are some similarities between a space shuttle and a nuclear power plant. This raises the questions if lessons can be learned from the Columbia accident in the nuclear field. The paper will compare main insights of the Columbia investigation with findings of the evaluation of the operating experience from German NPP and draw conclusions from this comparison. Main root causes of the Columbia accident are deficiencies in the operating experience feedback process, inadequate assessment tools and deficiencies in decision making of management. When comparing these results to German NPP operating experience similar patterns can be identified in the reportable events. This finding indicates substantial deficiencies in the overall operating experience feedback process, the proactive approach to safety problems and management techniques regarding adequate decision making with respect to safety. The investigation of the Columbia accident also identified those factors inside and outside the organisation which contributed to an environment in which the causes for the accident could develop. The main contributing factors addressed are major reduction of resources, schedule pressure, organisational culture, deficiencies in communication and ineffective safety office. Some of these factors can also be observed in the nuclear industry. At present, the operating experience from German NPP does not provide clear evidence to which extent these factors are impacting safety. Based on the findings of the Columbia investigation it can be assumed that these factors if existing are influencing safety of NPP too. Hints which can be gained from operating experience are supporting such a conclusion too.

1 INTRODUCTION

For nuclear facilities safety of the installations is of utmost importance. There is an international consensus that in addition to reliable plant and competent personnel efficient operating experience feedback shows itself to be an indispensable element to maintain and improve nuclear safety. Therefore, early in the development of the peaceful use of nuclear energy in the FRG an operating experience feedback system including foreign operating experience was implemented. Since the seventies, on behalf of BMU GRS is performing a comprehensive indepth analysis of the operating experience in particular of the reportable events. The main emphasis of this analysis is on the identification of the lessons to be learned and their relevance for german NPP.

When collecting material for this presentation the official report on the Columbia Space Shuttle accident issued by the Columbia Accident Investigation Board became available. The report contains a comprehensive analysis of the accident and it´s root causes. It provides interesting insights on how the accident could happen. A key area contributing to the accident are deficiencies in NASA´s operating experience feedback process.

On principle, there are some similarities between a Space Shuttle and a nuclear power plant. Both are complex technologies and both are making great demands upon safety. This raises the questions if lessons can be learned from the Columbia accident in the nuclear field. Therefore, the idea was born not to give another presention and discussion of statistics related to German operating experience in this paper. Instead, the presentation will take a look beyond the border of the nuclear field to compare main insights of the Columbia investigation with findings of the evaluation of the operating experience from German NPP and to draw conclusions from this comparison.

Chapter 2 provides a brief description of the Columbia accident and its causes. Chapter 3 compares main insights from the Columbia accident with results of the evaluation of German NPP operating experience. The conclusions from this comparison are drawn in Chapter 4.

2 COLUMBIA ACCIDENT

2.1 Description of the Accident

The last mission of Columbia and its seven crew members started on January 16, 2003 for a 17 days mission. At first, nothing extraordinary seemed to have happened during launch of the Shuttle. But early during the mission routine evaluation of images from the launch of Columbia revealed that a piece of insulating foam from the external tank had hit the Orbiter's left wing about 80 seconds after the start. In addition, the piece of foam identified was larger than pieces of foam observed during some former missions. This observation led to theoretical analysis and discussions if the debris strike could have damaged the Thermal Protection Shield of the space shuttle. Finally, the Mission Management Team took the decision that the safety of the Orbiter was not in doubt and that no additional measures were necessary for the re-entry of the Shuttle. The decision was merely based on theoretical considerations. Images of the left wing by a satellite or visual inspection by a crew member to confirm the decision taken were not deemed necessary and not carried out. On February 1, 2003 at about 9:00 60 km over Texas contact to Columbia was interrupted and destruction of the Orbiter occurred.

2.2 Causes of the Accident

The Columbia Accident Investigation Board performed a comprehensive investigation on the causes of the accident. This investigation included the technical causes as well as the underlying root causes. Since it is not possible to discuss all details of the investigation the focus in this presentation will be on the main findings.

2.2.1 Technical Causes

During launch, a space shuttle consists of three main parts: the Orbiter, an External Tank containing liquid hydrogen and oxygen and 2 Booster Rockets. The Orbiter is attached to the

External Tank by two “bipod” fittings at the bottom and one “bipod” fitting at the top. The External Tank is insulated by a foam to maintain an interior temperature that keeps oxygen and nitrogen in a liquid state.

The Accident Investigation Board concluded from the analysis of the data available, theoretical investigations and experiments carried out after the event that the insulating foam which detached during start of the shuttle severely damaged reinforced Carbon-Carbon Panels of the thermal protection shield at the underside of the left wing. Thus, during re-entry superheated air could enter into the inside of the left wing which finally destroyed the aluminium structure of the wing.

The foam insulation is mechanically sprayed on the External Tank. The adhesion between foam insulation and External Tank is quite good. But there are some regions with geometrically complex structure like the bipod ramp where the foam has to be sprayed on by hand. It was known from previous starts that these regions are prone to detachment of foam. The application of the foam was visually inspected but a non-destructive testing to detect subsurface defects or foam variability was not performed. The piece of insulating foam that hit the Orbiter during launch originated from the upper left bipod fitting of the Orbiter to the External Tank. The cause for this foam shedding could not be exactly explained by the Investigation Board after the accident, although the in-depth analysis revealed several findings that could have contributed to the loss of the insulation foam.

2.2.2 Root Causes

2.2.2.1 Deficiencies in Operating Experience Feedback Process

The Accident Investigation Board concluded that deficiencies in the operating experience feedback process are a key root cause of the Columbia accident. In particular, this finding is based on the lessons learned from the Challenger accident. But it is also based on the treatment of the foam shedding problem.

Challenger Accident

The Challenger accident which happened in January 1986 showed similar characteristics as the Columbia accident. The Challenger accident was caused by a failure of the joint and seal between the two lower segments of the right Solid Rocket Booster. At that time, weakness of that joint was a well known problem which had frequently recurred. Despite safety concerns, the joint had never adequately been tested, nor had a solution been developed. Instead, the problem was seen as an acceptable flight risk. When the decision was taken to launch Challenger in January 1986 during weather conditions outside the range of previous experience safety did not get the necessary attention. Communication failures, incomplete and misleading information, and poor management judgements contributed to the flawed decision. The deficiencies in safety awareness are illustrated by the fact, that management had required to prove that it was not safe to launch, rather than proving it was safe.

Though the root causes of the Challenger accident have been evaluated after the accident, the results of the Columbia Accident Investigation Board show that the corrective actions taken did not prevent the Columbia accident 17 years later. This is mainly due to lessons learned not or not effectively implemented and corrective actions taken back during the course of time.

Foam Shedding Problem

Early in the Space Shuttle Program engineers were extremely concerned about potential damage to the Thermal Protection System of the Orbiter due to foam loss. The behaviour of the reinforced Carbon-Carbon Panels under debris strikes has already been studied during the design of the Space Shuttle. The result was that a small damage of the Thermal Protection Shield would be no problem for the re-entry of the Orbiter. So the design required that shedding of foam debris from the External Tank had to be precluded in order to protect the Orbiter from any significant debris hit.

In reality, foam shedding was a problem from the beginning of Space Shuttle operation. About 80 % of the flights with photographic surveillance have shown a loss of foam isolation. In Space Shuttles history, six events similar to the one which caused the Columbia accident with foam loss from the forward bipod attachment, occurred. The first known bipod ramp foam loss happened during a Challenger mission in 1983.

Damage to the Thermal Protection System was classified as In-Flight Anomaly which means that the problem has to be solved before the next launch or it has to be proved that it does not threaten safety. In practice, such In-Flight Anomalies were closed by repair of the Thermal Protection System before the next flight. The cause of the damage, i.e. the shedding of the foam was not corrected. A comprehensive investigation to demonstrate that the foam shedding from the bipod ramp does not threaten safety was also not carried out. All action taken in the long history of foam shedding to prevent damage from the Space Shuttle have been fragmentary and insufficient and an adequate trend analysis of foam loss was missing.

The last event of foam shedding from the bipod ramp occurred in October 2002. This was the first time that the damage in the Thermal Protection System caused by the impact was not classified as In-Flight Anomaly. This illustrates that foam debris losses had developed in the perception from a violation of design requirements to a maintenance problem with no safety-of-flight concern.

2.2.2.2 Inadequate Assessment Tools

The existing model to predict potential damage to the Thermal Protection System by debris had been developed and calibrated for small debris. Though shedding of larger pieces of foam was observed in the past, this model was never adopted and verified for impact of large debris.

Therefore, when the evaluation of images from launch of Columbia revealed on flight day two that a large piece of insulation foam from the left bipod area of the External Tank had hit the Orbiter´s wing a reliable tool to predict the potential consequences to the Thermal Protection System was missing. In addition, a short time before the accident the responsibility for this type of analysis had been transferred to another team which did not have much experience.

Immediately after the information on the foam strike was spread there have been different concerns by Shuttle Program managers and working engineers about the potential damage. Therefore, the analyst who was responsible for the investigation started to calculate the damage that might have resulted from such a strike. He had only used the model twice before and it was the first time that the model was used for a mission that was on orbit. The analyst had reservations about using the model for the piece of foam debris that struck Columbia. The Results of his calculation seemed to be alarming since they did indicate a potential safety-of-flight risk. Nevertheless, due to the uncertainties in the model the analysis did not provide clear results what the possible damage could be.

2.2.2.3 Deficiencies in Decision Making

Despite the concerns about safety of the Orbiter due to the debris strike the responsible management took the decision that safety was not in doubt and no additional imagery or visual inspection by Columbia crew would be necessary to prove safety. Several aspects have contributed to this flawed decision making.

Very early in the Columbia mission an Debris Assessment Team has been formed in order to combine the different efforts and to evaluate the potential safety-of-flight risk from the foam debris. But the team did not get the correct organisational status. Therefore, its actions, requests and results were not managed by the normal formal procedure which led to major problems.

The analysis on the potential safety-of-flight risk from the foam debris strike performed by the Debris Assessment Team did not reveal clear results due to lack of an appropriate model and lack of experience of the analysts. In addition, though respective tools and requirements were existing the results presented to the management did not included a quantification of the range of uncertainties and a risk analysis. This information would have helped management understand the risk involved in its decision.

Communication problems contributed to the flawed decision too. As there have been no participants from the Mission Management Team, which is responsible for all decision making concerning the flight of Columbia, in the Debris Assessment Team there was no clear communication between the two teams. The Investigation Board identified that there was an unofficial hierarchy among NASA programs and directorates that hindered the flow of communications. The engineers who understood their system and related technology saw the potential for a problem on landing, but their concerns never reached the Mission Management Team. Later on managers claimed that they did not hear the engineers' concerns. In fact they did not ask and listen.

The attitude of the managers in the Mission Management Team can be best characterised by lack of awareness with respect to the potential significance of foam debris strikes. This may be partly explained by the organisational culture of NASA and the long history of foam shedding that did not cause any serious safety-of-flight problem.

The attitude of the Mission Management Team members may also have contributed to the lack of facts gathering for decision making. During the whole discussion on the potential significance of the foam strike, the Mission Management Team plaid a passive role. It did not take the leadership to manage proper evaluation of the problem by experienced engineers. Instead, the low level of concern of the Mission Management Team members was very resistant to arguments indicating the potential of a serious damage. It established a wall between the decision makers and the concerned engineers. Thus, the engineers found themselves in the position of having to prove that something is unsafe - a reversal of the usual requirement to prove that a situation is safe. This indicates, that the attitude in the organisation had changed from a critical attitude to everything that could threat safety of the Orbiter to a critical attitude to everything which could delay the schedule.

2.2.2.4 Contributing Factors

The Columbia Accident Investigation Board spent large efforts not only to identify the root causes of the accident but also to address those factors inside and outside the organisation which contributed to an environment in which the causes of the accident could develop. The main results of this part of the investigation are briefly summarised in the following.

Decreasing Political Support

After the end of Cold War in the late 1980s NASA lost a lot of its political support and the priority of several projects could no longer be justified by the superpower struggle. There was a constant pressure from White House, Congress and NASA leaders to reduce the cost or at least to freeze operating cost of Space Shuttle. This reduction had impacts on technical decisions, organisational structure and outsourcing. Since NASA falsely believed that Space Shuttle Mission had become routine responsibilities for Shuttle operation and safety was turned to a single prime contractor. As a consequence, NASA reduced its involvement in ensuring Shuttle safety and lost competence. The budget reductions for Shuttle operation resulted also in a declining support base of second and third contractors. These developments coincided with demands for additional resources due to greater maintenance requirements of the ageing Shuttle fleet.

Pending Decision on Space Shuttle Replacement

The decision on replacement of the Space Shuttle was pending for a long time and there was a big uncertainty how long the shuttle would fly before being replaced. This resulted in a delay of upgrades to make the shuttle safer and to extend its lifetime. Furthermore, the investments in Shuttle upgrades and in the infrastructure have been limited and inconsistent.

Organisational Culture

The organisational culture of NASA developed in the Cold War environment and can be characterised by an exceptional ´can-do´ culture. This culture was very resistant to changes. It never substantially changed and was never fully adapted to the Space Shuttle Program with its goal of routine access to space. As a consequence of NASA´s organisational culture significant deficiencies in its safety culture could develop. The insufficient root cause analysis of problems during the different missions led to engineers and managers getting accustomed to safety problems. This resulted in an environment in which engineers had to prove that something was unsafe instead of proving that something is safe.

The organisational culture also contributed to lack of adaptation of the overall program to the reality of budget which is characterised by the Investigation Board by “trying to do to much with to little”. With respect to Space Shuttle Program this resulted in loss of any margins to cope with unforeseen problems.

Schedule Pressure

Another contributing factor was an all-embracing schedule pressure due to the launch date of the last module to complete the U.S part of the International Space Station. If this launch date was not met, NASA would risk support from the White House and Congress for subsequent Space Station growth. This date seemed etched in stone and little by little NASA was accepting more and more risk in order to stay on schedule. Because of lack of any schedule margin, the schedule pressure created a climate in which safety concerns where just treated as threat to the schedule.

Deficiencies in Communication

Deficiencies in communication were identified as contributing factor too. There was a lack of a clear communication resulting in an insufficient flow of information between the different departments, from top to bottom and vice versa as well as in an inadequate process in handling problems or concerns. In addition, the transfer of responsibilities also created barries for effective communication.

Ineffective Safety Office

After the Challenger accident the investigation commission recommended to establish an independant Office of Safety, Reliability and Quality Assurance. Though such an office was created it never got the independance and authority recommended by the investigation commission. By the time, its independance and authority further deteriorated. During the final Columbia mission the safety representatives plaid a completely ineffective role. They attended all meetings of Debris Assessment Team and Mission Management Team but were always passive and silent.

3 NPP OPERATING EXPERIENCE

In this chapter the findings from the Columbia accident with respect to root causses are compared to results of German NPP operating experience. The chapter is following the structure of chapter 2. Each section is starting with a brief summary of the findings discussed in the respective section of chapter 2. Thereafter, German NPP operating experience highlighting similar root causes will be discussed. Since it is not possible to provide an exhaustive discussion of the respective operating experience in this presentation the paper has been limited to some examples.

3.1 Deficiencies in Operating Experience Feedback Process

The Columbia Accident Investigation Board concluded that deficiencies in the operating experience feedback process have been a key root cause of the Columbia accident. The main findings are: (1) lessons learned from a precursor event not effectively implemented and (2) a safety problem pending for a long time neither solved nor sufficiently analysed and thus becoming normality for the personnel by the time.

Similar characteristics can be found in reportable events from German NPP operating experience too. This will be illustrated by some examples.

Potential Interfacing Loss Of Coolant Accident

The event occurred in a Pressure Water Reactor in 1987. During start up, the first check valves in the residual heat removal system (RHRS) connection lines to the reactor coolant system hot legs have to be closed by disengaging the locking of valve stem in the OPEN position. When this step was performed in one train of the RHRS the CLOSED position was not indicated by the valve position indication. As the operators believed that the valve position signal and the alarm were incorrect they continued with plant start-up. There had been problems with the position indication of the check valves concerned from the beginning of plant operation. It was well known that the position indication was difficult to adjust and not reliable. The problem was not solved. Adequate investigation on potential consequences of a first check valve not closed and how to proceed in case of the CLOSED position not indicated had not been performed.

Some time later in the start-up procedure a high temperature alarm in the low pressure part of the let down line of the Chemical and Volume Control System (CVCS) was monitored. The reason was found in hot coolant passing through the first check valve and being released through a the safety valve into the CVCS let down line. The safety valve is attached to the RHRS line between first and second check valve to detect leakage through the first check valve. After detection of the leak the shift supervisor decided to shut down the plant. However a last trial was made to close the check valve by applying a differential pressure across the valve cone. For this purpose the isolation valve in the RHRS test line was opened. In the past when the check valve was leaking at start-up it could be closed by this action. The experience showed that the valve always was tight after that. But this time, the check valve did not become leaktight. The investigation performed after the event revealed that the valve was sticking open.

As a consequence, high pressure and temperature primary coolant entered the low pressure part of that RHRS train and caused the opening of a safety valve in the test line releasing primary coolant into the annulus outside the containment. The loss of coolant was stopped by closing the isolation valve in the test line. The event raised serious safety concerns because of its potential for an Interfacing Loss of Coolant Accident, in particular since the test line was not designed for high pressure and temperature primary coolant.

In the course of analysis carried out after the event a similar event in this plant was found which happened about 10 years ago without taking the appropriate corrective actions.

Inadvertent Boron Dilution in Refuelling Water Storage Tanks

In 2001, during start-up of a PWR part of the water volume of the refuelling water storage tanks of three trains of the emergency core cooling system was inadvertently refilled by demineralised water instead of borated water. This was not recognized by plant staff and the plant went into power operation. Cause of the event was the wrong position of a manual valve in the boron acid and demineralised water injection system. In the past there have been some problems with the valve. The position of the valve was difficult to determine and occasionally the valve was sticking due to boron acid deposits. This had not been resolved.

About 14 days later the personal noticed the error and started to correct the boron concentration in the refuelling water storage tanks which took more than one week. First analysis carried out immediately after identifying the error gave the result that the boron concentration in the refuelling water storage tanks concerned was below the requirements but sufficient to ensured a sub-criticality in case of a Loss of Coolant Accident. Since the Technical Specification were not precise for such a case, it was decided to go on with power operation and not to shut the plant down.

Investigation performed after the event revealed that the first analysis was flawed. The analysis was based on optimistic assumption and did not properly take into account the actual conditions and the different phenomena with respect to boron dilution like stratification. Therefore, from a safety point of view shutdown of the plant would have been demanded.

The safety concern with respect to the event is the potential for re-criticality of the reactor in case of a Loss of Coolant Accident. Though in-depth analysis and experiments after the event revealed that for the conditions of the event re-criticality of the reactor in case of a Loss of Coolant Accident would not occur, re-criticality in case of a Loss of Coolant Accident could not be excluded under different boundary conditions.

Like in the first example, investigation after the event showed that the event was preceded by another event about a year before where demineralised water was erroneously injected into the spent fuel pool due to wrong position of the same valve. This event was not judged as safety significant. Thus it had not been analysed in-depth and no corrective actions had been implemented.

Radiolysis Gas Detonation

In 2001, several alarms occurred in the control room of a Boiling Water Reactor during full power operation indicating a steam leakage inside containment at the reactor pressure vessel head spray (RPVHS) line. The leakage could be manually terminated by closing a valve in the drain line of the RPVHS line. Immediately after the event shift personnel reduced the reactor power. After first analysis, the operating staff assumed that only a small leak at a flange in the RPVHS line had occurred. Therefore, full power operation was resumed. Based on their assumption of a flange leakage operating staff decided not to enter the containment for an in-situ inspection of the affected location.

After the event until end of January 2002, the utility performed respectively ordered further analyses aiming to justify the assumption of a flange leakage, i.e. overall integrity of the RPVHS line. In the course of the investigation performed after the event, the licensee came to the conclusion that the measured data, alarms and indications during the event could not consistently be explained by the original assumption of a small spontaneous seal leakage at one of the RPVHS line flanges. Therefore, further causes were taken into account, in particular water hammer and radiolysis gases reaction. Radiolysis gases reaction was ruled out because analyses at that time showed that in case of a radiolysis gases reaction pressure was not high enough to damage the RPVHS line. Thus, investigations focussed on water hammer. But until mid February still open questions existed to explain the alarms of the limit switches of the containment isolation valves and the temperature history in the RPVHS line.

Therefore, on February 18, 2002, the reactor power was decreased to visually inspect the RPVHS line inside the containment. The visual inspection of the RPVHS line revealed that part of the RPVHS line between the check valve at the reactor pressure vessel and the inner containment isolation valve was completely destroyed. In-depth analysis performed after this finding concluded that the damage had been caused by a radiolysis gases reaction. Due to untightness of the containment isolation valves of the RPVHS line and some degradation of the draining capacity of the drain line water accumulated in the lower part of the RPVHS line. This led to substantially higher accumulation of radiolysis gases in the RPVHS line than predicted by theoretical calculations. The ignition mechanism could not clearly be identified by the in-depth analysis.

Events related to radiolysis gases reaction have a long history in German and foreign BWR operating experience. To prevent recurrence of such events, corrective actions such as catalysts and temperature monitoring devices were implemented in some areas of German BWRs in the late 80ies. Later on, due to operating experience the scope of corrective actions was extended step by step. In 1999, a further event caused by radiolysis gases explosion occurred at the plant affected. After that event, a review of the measures implemented to cope with radiolysis gases accumulation was made. Additional measures were taken if deemed necessary. The criterion taken to decide on the need of measures in a specific area was that all of the following three conditions are fulfilled: (1) ignitable radiolysis gases can accumulate, (2) possible ignition sources are existing, and (3) the component strength against possible radiolysis gases reaction pressures is not sufficient. Due to the analysis no additional measures had been taken for the affected part of the RPVHS, because no possible ignition source had been identified. One cause among other things was, that the analyses conducted assumed undisturbed as designed conditions and did not consider possible deviating boundary conditions or disturbances to the necessary degree.

International Operating Experience

Recurrence of significant events because of deficiencies in the operating experience feedback process are of international concern since many years. This includes existing operating experience not sufficiently evaluated, lessons not or not adequately learned, and corrective actions not, not timely or not effectively implemented. Therefore, NEA´s CSNI working group on operating experience has performed a generic study on recurring events due to deficiencies in the operating experience feedback process based on information available in the IRS. The results of this study will be published soon. They underline the importance of the respective findings of the Columbia root cause analysis for NNP.

3.2 Inadequate Assessment Tools

After the start of COLUMBIA and detection of the loss of insulating foam, theoretical analyses on potential impacts were initiated. But the existing model for assessing damage by debris strikes was not adopted and verified for large pieces of foam such as observed during launch of Columbia. Therefore, the analysis performed using this model deemed to have a high degree of uncertainty and thus did not provide clear results.

Lack of appropriate assessment tools can also be identified in the second example in section 3.1 related to the erroneous injection of demineralised water into borated water storage tanks of the ECCS. Boron dilution phenomena are under investigation since several years, e.g. to assess the safety significance of the reflux condenser mode during Small Loss of Coolant Accidents or of inadvertent demineralised water injection into the reactor coolant system during shutdown modes. Though models for assessing boron dilution phenomena were existing at the time of the event, they were lacking verification in particular with respect to the specific boundary conditions prevailing during the event. Thus, when a short-term assessment of the safety impact had to be performed a simple model (homogeneous mixing) and optimistic assumptions have been used. This approach led to flawed results which became evident by the in-depth analysis carried out later on.

But wrong assessment of the safety significance is not limited to lack of appropriate assessment tools. Lack of sufficient and timely in-depth evaluation of existing operating experience may result in a similar situation when a short-term assessment is required for a complex situation in the course of an event. This is illustrated by the two other events discussed in section 3.1. In both events the phenomena important for safety are complex. On principle, the tools to assess these phenomena were existing. But in these events respective former operating experience had not or not sufficiently exhaustive been evaluated. Thus, operating staff was not sufficiently prepared and came to wrong conclusions when a short-term judgement had to be taken.

3.3 Deficiencies in Decision Making

The flawed decision taken by the Mission Management Team was caused by flawed analysis, blocked or ineffective communication channels, missed opportunities, insufficient information basis, ineffective leadership and lack of awareness.

Deficiencies in decision making are also highlighted by the examples from German NPP operating experience discussed in Section 3.1. In all three examples the information basis for an adequate assessment of the potential implications for safety was not sufficient. As shown by in-depth analysis carried out later on, in all three examples a decision was taken which was not adequately reflecting safety aspects.

For all three events there have been precursors which were not sufficiently investigated. This ranges from lack of analysis to in-depth analysis not taking into account unfavorable boundary conditions. Thus, plant staff was not adequate prepared when a short-term judgement had to be taken.

Lack of awareness and deficiencies in leadership can be observed in particular in the first examples. The unsafe action taken by operators during the event was a result of a long experience and the thought that there will be no problem. Negativ consequences were not taken into consideration. The example illustrates the degradation of awareness by previous operating experience and practices which did not lead to a safety problem. The other two examples are showing lack of awareness and deficiencies in leadership too. An indication is that the assessments performed for decision making was too narrowly focussed and did not consider all relevant aspects.

3.4 Contributing Factors

The Columbia Accident Investigation Board addressed a number of factors inside and outside the organisation which contributed to the environment in which the causes of the accident could develop. Some of these factors can also be observed in the nuclear industry.

Since some years, there are large efforts to reduce operating costs of NPP. This includes reduction of staff both at headquarters and plants as well as reduction of budgets. As a consequence, outsourcing, i.e. the number of tasks performed by contractors is increasing. There are also efforts to reduce costs in the technical area, part of which are taking credit of “unnecessary” safety margins. Other factors that can be observed are pressure on plant operation due to economic reasons and discussion on the need of investment in plant equipment and staff taking into account the agreement on phase out of NPP.

At present, the operating experience from German NPP does not provide clear examples that these factors are significantly impacting safety. But there are indications from operating experience that problems may rise. Important areas are staffing and competence of the operator to adequately supervise contractors and keep its responsibility for safety. There are also signs of decreasing competence of contractors with respect to safety aspects which may impose additional requirements on staffing and competence of the operator in contrast to the development observed today. The same is valid for the decreasing basis of contractors which increases dependance and vulnerability. Therefore, these trends have to be carefully monitored and evaluated to prevent unfavorable develeopments for nuclear safety.

4 CONCLUSIONS

The evaluation of the Columbia accident revealed a substantial number of root causes and factors which contributed to the accident. Main root causes identified by the Columbia Accident Investigation Board are deficiencies in the operating experience feedback process, inadequate assessment tools and deficiencies in decision making of management. When comparing these results to German NPP operating experience similar patterns can be identified in the reportable events. This finding is not limited to events which occurred in the early years of the use of nuclear energy. There are significant events in the last years showing these patterns too. Applying the conclusions drawn from the investigation of the Columbia accident this finding indicates substantial deficiencies in the overall operating experience feedback process, the proactive approach to safety problems and management technics regarding adequate decision making with respect to safety.

The Columbia Accident Investigation Board spent also large efforts to address those factors inside and outside the organisation which contributed to an environment in which the causes for the accident could develop. The main contributing factors identified are major reduction of resources (stuff and budget), schedule pressure, organisational culture, organisational problems in particular deficiencies in communication and ineffective safety office. Some of these factors can also be observed in the nuclear industry. At present, the operating experience from German NPP does not provide clear evidence to which extent these factors are impacting safety. The reason is that in-depth analysis addressing this factors like the Columbia investigation did are not carried out. Based on the findings of the Columbia investigation it can be assumed that these factors if existing are influencing safety of NPP too. Hints which can be gained from operating experience are supporting such a conclusion too.