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Nuclear Power Plant Operating Experiences from the IAEA/NEA Incident Reporting System

2002-2005

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

INTERNATIONAL ATOMIC ENERGY AGENCY

The International Atomic Energy Agency (IAEA) serves as the world's international governmental forum for scientific and technical co-operation in the peaceful use of nuclear technology. Established as an autonomous organisation under the United Nations (UN) in 1957, the IAEA represents the culmination of international efforts to make a reality of US President Eisenhower's proposal in his "Atoms for Peace" speech to the UN General Assembly in 1953. He envisioned the creation of an international body to control and develop the use of atomic energy. Today, the Agency's broad spectrum of services, programmes, and activities is based on the needs of its 139 Member States.

Technology transfer

The Agency works to foster the role of nuclear science and technology in support of sustainable human development. This involves both advancing knowledge and exploiting this knowledge to tackle pressing worldwide challenges – hunger, disease, natural resource management, environmental pollution, and climate change. A substantial part of the Agency's work relates to nuclear power, including its safety and waste management, and ensuring that nuclear technology is being used only for peaceful purposes.

Where appropriate, the IAEA facilitates transfer of nuclear technology to Member States for use in medical, agricultural, industrial, water management, and other applications. Many of these programmes contribute directly or indirectly to the goals of sustainable development and protection of the environment set out in "Agenda 21", of the 1992 UN Conference on Environment and Development. The Agency also has two scientific laboratories where training and research are performed in support of technical co-operation and assistance activities. Many of these activities are conducted in conjunction with the Food and Agriculture Organisation (FAO). The Agency cooperates in a joint division with the FAO, promoting applications of isotopes and radiation in food and agriculture. This includes such areas as plant breeding and genetics, insect and pest control, soil fertility, irrigation and crop production, animal husbandry, and food preservation.

Nuclear safety

The future role of nuclear energy depends on a consistent, demonstrated record of safety in all applications. Although the IAEA is not an international regulatory body, its nuclear safety efforts are directed towards creating multilateral, legally binding agreements, which are increasingly important mechanisms for improving nuclear safety, radiation safety, and waste safety around the world. IAEA safety recommendations are used by many countries as a basis for domestic standards and regulations. Codes of practice and safety guidelines have been developed for the siting design, operation, and quality of nuclear power plants. To strengthen worldwide operational safety further, the Agency performs safety evaluations on request, including on-site review of nuclear power plants by international expert teams.

Non-proliferation of nuclear weapons

As part of the global effort to prevent the proliferation of nuclear weapons, the IAEA verifies that nuclear materials are not diverted away from legitimate peaceful use for military purposes. Once a Member State becomes a party to a safeguards agreement, the Agency's inspectors monitor all declared nuclear material through on-site inspections, remote surveillance, and record verification. Without this systematic safeguards system, trade and technology transfer of nuclear applications would not be possible. To date, there are 223 safeguards agreements in force with 139 states. The IAEA safeguards role is being further strengthened to allow greater detection of any potential diversion of nuclear material.

FOREWORD

Incident reporting has become an increasingly important aspect of the operation and regulation of all public health and safety-related industries. Diverse industries such as aeronautics, chemicals, pharmaceuticals and explosives all depend on operating experience feedback to provide lessons learnt about safety.

The Incident Reporting System (IRS) is an essential element of the international operating experience feedback system for nuclear power plants. IRS reports contain information on events of safety significance with important lessons learnt which assist in reducing recurrence of events at other plants. The IRS is jointly operated and managed by the Nuclear Energy Agency (NEA), a semi-autonomous body within the Organisation for Economic Co-operation and Development (OECD), and the International Atomic Energy Agency (IAEA), a specialised agency within the United Nations system. In order for the system to be fully efficient, it is essential that national organisations allocate sufficient resources to enable timely reporting of events important to safety, and to share these events in the IRS database.

This third report on nuclear power plant operating experience from the IAEA/NEA Incident Reporting System covering the 2002-2005 period follows on the success of the previous two covering 1996-1999 and 1999-2002. This edition highlights important lessons learnt based on a review of the approximately 200 event reports received from the participating countries over this period.

This report is intended to provide senior safety managers in regulatory bodies and in industry with information related to the safety of nuclear power plants to help them in their decision-making role.

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EXECUTIVE SUMMARY

The main purpose of the "Blue Book" is to provide senior managers in regulatory bodies and the nuclear industry with safety-related information, gathered by the IRS community during the period 2002-2005, which should help them in their decision-making roles.

During the 2002-2005 period, experts involved in operating experience feedback gathered in international fora (working groups, symposia), sponsored topical studies to review safety information and issues identified mainly in the incident reporting system (IRS) and draw lessons for the benefit of the international community. The main lessons learnt from the IRS selected events, and studies performed during that period are briefly summarised below.

Part I: The Incident Reporting System (IRS)

The Incident Reporting System (IRS) is the only international reporting system managed by nuclear regulatory authorities around the world. It is jointly operated by the IAEA and the OECD/NEA. Over the last 25 years, the IRS has gathered more than 3 250 reports on safety-significant events that have occurred at nuclear power plants from the participating countries.

The IRS ensures proper reporting and feedback of safety-significant information so that the causes and lessons learnt widely disseminated. Therefore, the IRS contributes to the prevention of occurrence or recurrence of incidents.

In providing the world safety experts and managers with information on individual and generic issues of safety significance, the IRS, together with other systems, contributes to the prioritisation of issues important to safety and assists in the identification of areas where further improvements, resources or research is appropriate.

Part II: Events and experience gained from the IRS during the reporting period

During the reporting period, almost all events discussed by the IRS community were due to well-known phenomena. It means that in spite of the information exchange mechanisms in place at both national and international levels, corrective measures that are generally well-known are not always rigorously applied. That aspect requires closer examination because it reveals a deficiency in the operating experience feedback loop.

Among the contributing factors to the events recently reported to the IRS, there are, beside technical reasons, many human and organisational related topics, e.g.: quality and safety management, lack of knowledge, complacency, procedures, work organisation, influence of contractors, maintenance and modification deficiencies, and other issues related to the adequate utilisation of the available information on operating experience feedback.

The IRS database contains instances of recurring events with a long history, some of them as long as 20 years ago, such as failures of residual heat removal system. Most of the events that are summarised in Part II may be regarded as recurrent events and several lessons, which can be learnt from these events, are suggested hereafter.

Lessons learnt from **electrical grid disturbances and/or losses of offsite power** are that these events revealed deficiencies in a number of plant safety systems, including emergency service water, fixed fire-fighting systems, and standby generators as well as opportunities for improvements in the licensing basis. Therefore they lead to deterioration of plant defence in-depth and as such, these events are considered as high risk-significant. In light of recent developments in the opening of electricity markets to competition, particular attention should be paid to analysing electrical grid stability together with availability of power plant safety systems, as well as problems of communication between plant operators and grid operators.

Failures of fuel assemblies show that, in addition to leading to long plant shutdowns and loss of electricity production, they may have potential serious consequences in terms of contamination and nuclear safety. Therefore it appears that a rigorous and thorough risk analysis is a prerequisite to any design modification of fuel assemblies or devices utilised in fuel-related activities. Furthermore, deficiencies in maintenance procedures and absence of post maintenance checks may induce foreign material intrusions and result in fuel degradation. As a matter of fact, the prerequisite to any design modification is a lesson learnt in common with other deficiencies as demonstrated later by fire-related events.

The main lessons from **intrusion of foreign material,** particularly in the primary system, is that despite changes and improvements in working methods and QA programmes they continue to occur. The main causes imply human actions, organisational and QA management failures and their consequences range from minor to major damages. This issue deserves more oversight from both plant management and regulators.

Lessons learnt from **secondary system piping degradations** show that the industry guidance to predict onset and severity of the potential for wall thinning may not be working properly, and the regulatory oversight may be insufficient. The piping degradation events remind one of the necessity to fully assess all precursor events, to implement timely corrective measures and to periodically assess their adequacy and completeness.

As already reported to the IRS in the past years, the corrosive impact of boric acid on ferritic steel has been evidenced once again in a recent event implying **reactor pressure vessel degradation**. This problem is of particular concern for the reactor pressure vessel and primary coolant system. The management of that particular event shows that compliance with regulatory requirements and strict application of adequate surveillance programmes on the primary coolant equipment and system contribute to prevent occurrence of non-isolable primary coolant leak.

Lessons learnt from events during **mid-loop operation** show that this operation mode is error-prone and despite many modifications implemented for more than twenty years to reduce the risk against residual heat removal system failures, inadequate procedures, inadequate instrumentation and alarms, as well as wrong operator actions remain the main challenges to the resolution of that issue. Licensees and regulators should pursue their efforts to decrease further the frequency of this type of event.

The main lessons learnt from **essential service water system failures** are linked to corrosion surveillance, inadequate procedures and operator actions, which constitute the main contributors to these events. Their impact may be significant on both potential common cause failures of redundant safety systems and interaction between safety and non-safety systems, which may not be sufficiently covered in the original plant design. In that respect, reliability of essential service water system has to be treated on a plant-specific basis given the large variety of differences in the design of the plants/systems.

Lessons learnt from **loss or failure of uninterruptible power systems** show that they may lead to breach the defence-in-depth and operate the plant under unanalysed safe conditions. They may also lead to negative consequences on the large conventional equipment such as the main turbine, and the generator if lubrication is lost. They encompass corrective actions not implemented and deficiencies in manufacturing and QA processes. These occurrences reflect the need for licensees to comply with and regulators to ensure compliance with maintenance rules and safety management systems.

Lessons learnt from reported **fire-related events** highlight the risk induced whenever plant-specific characteristics are not adequately considered at the design stage and risk analysis on fire fighting is not conducted as a part of the safety analysis before a modification. They also reinforce the need to implement corrective actions without undue delay and to pay particular attention to fire fighting training programmes.

Part III: Insights from studies, specialist meetings and workshops

Recurring events and follow-up with corrective actions related to a recurring event: Loss of the residual heat removal system at mid-loop

Recurring events imply many safety issues, notably design problem, deficiencies in the plant safety culture, and gaps in the national and international operating experience feedback systems. The study gives an exhaustive picture of the corrective actions applied to overcome recurrent events related to loss of the residual heat removal system. A major outcome is that corrective actions have succeeded in significantly lowering the recurrence of mid-loop conditions. However, it has taken about ten years to achieve a significant reduction in event frequency. Safety managers and authorities might consider the extent to which an emerging problem, such as the mid-loop operation was twenty years ago, has been given the appropriate attention for timely resolution of the issue. It is also of importance to consider the somewhat sparse nature of corrective actions that are described in the IRS reports. More improvements are needed here.

Modifications at nuclear power plants – Operating experience, safety significance and the role of human factors and organisation

Whilst there are a number of studies under way on this topic, a co-ordinated approach may yield greater benefits on awareness and understanding of the problems that modifications could cause to the plant personnel when they are not given proper attention. Such work might concentrate on collecting experience from actual modification projects and from events following modifications to create better guidance for the nuclear utilities and regulators. A particular aspect concerns minor and non-identified modifications, which may be introduced in different ways, and when overlooked or not recognised could generate common-cause failures influencing multiple layers of safety barriers. Plant personnel, manufacturers and contractors must be sensitised to small changes in components and materials. Minor and temporary changes present their own challenges for the nuclear power plants. While regulators and their technical supports have neither the capability nor the role to know everything about the modifications implemented either by the plant operator or by a manufacturer, they must ensure that utilities remain responsible for the safety management of all modifications.

Study on analysis of cracking and corrosion in passive components of the primary reactor coolant pressure boundary

Of the various forms of stress corrosion and cracking discussed, the topical study underscores the fact that most of the causes are plant design and operational issues, poor design, construction or support structures. While some of these failures are considered resolved, the continuing occurrence of some of these failure phenomena also underscores the importance of preventive measures based on improved plant design and operation, in-service inspections to detect affected regions, prompt detection and correction of primary coolant leakage.

Study on closing the feedback loop from events to definite elimination of the causes

While it is largely recognised that the IRS plays an essential role in ensuring proper reporting of safety-significant events and disseminating widely the lessons learnt, useful complementary tools can be combined with the operating experience feedback process to help in eliminating the causes of events and achieving safe operation. These are notably: a) instituting a system for learning from low-level events, precursors, near misses, deviations... b) use of PSA, c) use of periodic safety review, d) features in design, operation, maintenance and management. All these can be reviewed by Member States for appropriately incorporating them in their systems, practices and procedures. Additional efforts from the international community as well as Member States may be needed for better closing the feedback loop. In particular, a methodology could be worked out to share experience about the reporting systems of low-level event/deviation/near misses/precursors that many countries have implemented. A greater use of the results of the IRS topical studies would be extremely beneficial to the nuclear community.

International Common-cause Data Exchange (ICDE) Project

The main outcome from the reports issued by 2005 shows that for all components, about two thirds of all complete CCF events (i.e., events failing all the redundant components) involve faulty actions by plant personnel and contractors. The role of human action also increases with the number of redundant components. The single largest contribution is from faulty testing and maintenance work due to deficient and/or incomplete procedures. Another cause is from insufficient work control. They could be corrected by better procedures and control/maintenance practices. Main areas for improvement against CCFs according to ICDE project are the following: 1) scrutinising existing operation, maintenance and testing procedures for deficiencies creating the potential for CCF of redundant systems, 2) ensuring comprehensive work control, 3) comprehensively prescribing the steps of testing required in the requalification of components or systems after maintenance, repair or backfitting work, and 4) intensifying operator training, introducing ergonomically better designs and introducing more key locks.

Strainer clogging issue

The 2004 workshop on strainer clogging issues concluded that the safety significance of the sump strainer clogging depends on the plant design (e.g. sump strainer, emergency core cooling systems) and backfitting measures performed. Many design features of pressurised water reactors that could influence the impact of debris on sump strainer performance have been identified. Previous studies and workshops have demonstrated that sump strainer clogging may substantially increase the total core damage frequency. Research efforts should be aggressively pursued so as to accelerate the resolution of the sump strainer clogging issue.

Events including contractor and sub-contractor influence

Regulators and utilities expressed a common concern related to the increased use of contracting companies, which may lead to gradual loss of experienced and competent personnel in nuclear technology and results in weakening of nuclear field organisations. They recognised that licensees need to develop strategies for dealing with diversified contracting organisations that are becoming more global. They need to improve their own knowledge in order to conduct more technical work in-house or to become more intelligent customers. Certain core tasks cannot be outsourced and they must be conducted by the licensee staff (international guidance is needed on what are those tasks). Regulators need to develop their practices for verifying adequate arrangements between licensees and contractors to ensure that safety management of the tasks on-site remains in the hands of the licensee. It is also noted that in some areas, notably decommissioning, contracts are being awarded for “turn key” solutions, with the potentially for the task being carried out a contractor with no previous knowledge or experience of either the site or nuclear work. The regulators should consider whether their regulatory structure and powers are suitable for the challenge this could present. Both regulators and licensees agreed that proper attention should be given to the possible loss of knowledge due to merging of companies and the risk of disappearance of internal global oversight and overall plant safety responsibility ownership.

Safety performance indicators: Observations on operating reactor safety and efficiency performance

There is a quite large consensus on the fact that SPIs are a tool to aid in decision making among other complementary sources of information on licensees' early declining of their safety performance. Therefore, building indicator systems is not in itself an objective. Rather, the indicator system should be constructed so that indicators would provide decision makers with as much good quality information as possible for a variety of safety related decision-making situations. Although there was no agreement about what the indicators of safety management and especially safety culture are or could be, participants agreed that looking for indicators for human and organisational performance and safety management effectiveness is indispensable. A "universal comparative SPI set" would not be relevant and that extreme caution is required when SPIs are compared.

All these works have been carried out based on data reported to the IRS. In order to continue to serve the needs of persons responsible for safety and to provide the world experts with information on safety significance issues, some aspects of the reporting process need to be improved.

The decrease in the number of IRS reports does not necessarily reflect a deterioration of the IRS system. However, managers at national level should make sure that all safety relevant events are duly reported to the IRS.

Non-reporting of recurrent events reflects deficiencies in the operating experience feedback systems, which include national and international reporting systems including the IRS. That aspect deserves intensified oversight.

Many seemingly insignificant events occur daily in nuclear power plants, which are not seen as significant. Their safety significance may become obvious when these events are grouped together and analysed. This approach, not applicable with the existing reporting criteria to the IRS, presents a challenge for the future of the system.

National decision makers have an essential role in considering the above aspects, and in allocating appropriate resources to the IRS activities within their organisations so as to further improve the usefulness of the system and increase the safety benefits for all Member States.

1. THE INCIDENT REPORTING SYSTEM (IRS)

1.1 The IRS system

Twenty-seven years ago, Member States of the OECD/NEA agreed to set up an international reporting system to share lessons learnt from significant events (see Appendix). The Incident Reporting System (IRS) was designed as a tool for exchanging lessons learnt from unusual events which occurred in nuclear power plants. As soon as November 1983, Member States agreed that the IRS should be jointly operated by the IAEA and the OECD/NEA. The IRS compiles information and analyses on events in nuclear power plants and promotes a systematic approach to the feedback of lessons learnt from operating experience. The goal of the IRS is to ensure proper reporting and feedback of safety-significant events in nuclear power plants for the international community, so that the causes and lessons learnt can be disseminated widely and the frequency and severity of safety-significant events at nuclear power plants reduced. In this way, the IRS plays an important role in contributing to the prevention of occurrence or recurrence of incidents.

The role of the IRS was reinforced by the obligation under Article 19 of the Convention on Nuclear Safety that Contracting Parties take the appropriate steps to ensure that “programmes to collect and analyse operating experience are established, the results obtained and the conclusions drawn are acted upon and that existing mechanisms are used to share important experience with international bodies and with other operating organisations and regulatory bodies”.

Recognising the importance of sharing experience pertaining to operational events in nuclear power plants, the IAEA and the OECD/NEA have co-sponsored, in the framework of the IRS activities, international joint meetings dedicated to the exchange of information on recent events of safety significance. Participants have highlighted the importance of these meetings for improving the safe operation of nuclear power plants, as well as the need to increase the information exchange between regulators and utilities. The meetings of the IRS national co-ordinators are conducted annually to review the IRS operation and the analytical activities performed in the framework of the IAEA and the OECD/NEA programmes.

Participating countries

Argentina	Hungary	Slovakia
Armenia	India	Slovenia
Belgium	Italy	South Africa
Brazil	Japan	Spain
Bulgaria	Korea, Republic of	Sweden
Canada	Lithuania	Switzerland
China	Mexico	Ukraine
Czech Republic	Netherlands	United Kingdom
Finland	Pakistan	United States of America
France	Romania	
Germany	Russian Federation	

1.2 How can senior safety managers use and benefit from the IRS?

Safety managers in the industry, regulatory bodies and nuclear organisations around the world face a new challenging environment of deregulation, privatisation of the electricity generation, transmission and distribution systems, economic pressures and increased competition in the market place. This commercial environment common to other industries forces managers to seek new strategies and manage risks and resources with the objective of producing electricity while complying with regulatory requirements and maintaining a high level of safety. The IRS plays an important role in this regard by providing information on safety-significant events from the global nuclear community.

In managing risks and resources, safety managers need credible and reliable information on the systems they manage, in particular areas of high risk, in order to prioritise their programmes accordingly. They need to receive early warning of deteriorating safety performance in the field to address it and maintain the level of safety. They also need to share experience and lessons learnt with others, thus making more efficient use of their resources since their own experience base may be too limited to capture the spectrum of possible events and their contributors. In regulating the industry, regulators require the industry to report on hazards or potential for hazards so they can tailor effective requirements, guides, or standards in a manner limiting the risk to the public.

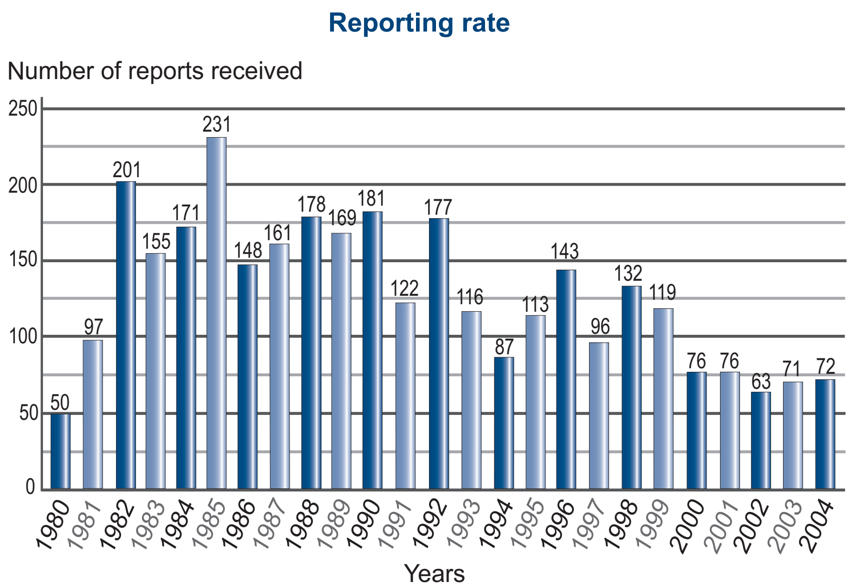
The IRS is one of the tools that can be used to serve current and future needs of senior safety managers. It can provide the world experts with information on individual and generic issues of safety significance, and advance information on deteriorating safety performance. The IRS can also be used, together with other databases, to help to prioritise those issues of safety significance that have been reported and to assist in the identification of areas where further resources or research is appropriate. The IRS is a global contact network and forum, which enables safety experts around the world to share and review information lessons learnt from events, which have been reported.

1.3 Reporting to the IRS

The system is based on the voluntary commitment of the participating countries and each participating country contributes to the system by reporting events and benefits by receiving operating experience reported by other countries.

Events reported to the IRS are those of safety significance for the international community in terms of causes and lessons learnt. The main objective of the IRS is to assure proper feedback on events of safety significance on a worldwide basis to help prevent occurrence or recurrence of serious incidents or accidents.

Currently, the IRS contains more than 3 250 reports gathered from the participating countries over the past 25 years. The annual reporting rate since 1980 is shown in the graph below.



The general quality of the reports exchanged through the IRS has improved over the years. Concurrently, the reporting rate has however generally diminished and in particular over the last five years. During the reporting period, about 70 events have been are reported per year, from a family of about 440 reactors (about 0.16 events per reactor-year; the original goal was 0.5 reports per reactor-year). Even assuming that the number of reportable events within each Member State has decreased over this time, the reduced amount of resources devoted to IRS activities in some Member States explain more likely this decrease. The decision makers' role in allocating appropriate resources to the operating experience and IRS within their own organisations is, therefore, essential in obtaining safety benefits for all Member States.

The second concern that has arisen is related to the non-reporting of recurrent events (a definition, as well as some examples of recurring events, is given in Section 3.1.4.). Recurring events are important to safety since they can indicate design problem, deficiencies in the plant safety culture, gaps in the national operating experience feedback systems, loss of continuity in skilled and knowledgeable operations and engineering staff, or lack of attention to design and operational factors such as plant ageing. It is therefore increasingly important for each Member State to report all events of safety significance, including their recurrence, to the IRS.

Finally, many seemingly insignificant incidents occur daily in nuclear power plants around the world. The safety significance of these may not be seen in any single incident by itself, but can be seen when incidents are grouped together and be subjected to systematic statistical and trend analysis methods. That approach is not applicable with the current reporting criteria to IRS and presents a challenge for the future of the system.

1.4 Data storage and retrieval

The reported data is maintained in a system for data storage and information retrieval known as the Advanced Incident Reporting System (AIRS) database. Events reported by the participating countries are transcribed to a CD-ROM, which is regularly updated and sent to the national IRS co-ordinators by the IAEA on a quarterly basis. Nowadays, this storage and retrieval system is outdated.

A web-based IRS is being developed by the joint IRS Secretariat that will be made available to the participating countries through their IRS co-ordinators around the world. It is a common view that the new web-based IRS will ease the task of the IRS coordinators for reporting unusual events and contribute to reverse the low reporting rate trend. Furthermore, the system will help the Secretariat to speed up the treatment of, and the search of various items in the IRS reports.

2. EVENTS AND EXPERIENCE GAINED FROM THE IRS DURING THE REPORTING PERIOD

2.1 Experience with electrical grid disturbances

Several electrical grid disturbances leading in some case to total losses of offsite power have been reported to the IRS in the recent past years. Grid disturbances may occur because of multiple causes such as equipment failure, overloading, lack of maintenance, human errors, etc., and may lead to a trip of both the turbo generator and reactor. Once the reactor has tripped, the plants rely on their back-up power sources, e.g. diesel generators, gas turbines and batteries to bring the reactor to a safe shutdown state. The design basis of nuclear power plant provides generally the necessary protection for this kind of events.

Electrical grid disturbances may also lead to loss of offsite power including loss of electricity distribution (characterised as blackouts) in the countries involved. They may also propagate into parts of the neighbouring countries because national grids are nowadays largely interconnected. As shown in recent large electrical grid disturbances that occurred in several countries, these events induce unnecessary and widely distributed challenges to safety-related systems of nuclear power plants.

Safety significance

These events are considered risk-significant because they challenge multiple safety systems of nuclear power plants. In particular, nuclear power plants need power for the safety equipment, which is supplied by emergency diesel generators, in order to reach a safe shutdown state. The operating experience and risk analysis show that the level of defence-in-depth of the nuclear power plants is reduced during a loss of offsite power scenario.

Lessons learnt

The loss of-offsite power events have, in some cases, revealed deficiencies in a number of plant-safety systems, including emergency service water, firewater, and standby generators, as well as highlighting opportunities for improvements in the licensing basis.

These events have common messages such as:

i) The event scenarios have not been adequately analysed at the design stages and, in some cases, there was a weakness in the ability to supply offsite power from diverse independent sources.
ii) The deficiencies have indicated the need to make significant changes in operating procedures and maintenance programmes for safety equipment in order to enhance their availability.
iii) Interconnected grids are subject to weaknesses when large concurrent trips of generating capabilities occur.
iv) Poor communications between utilities and grid operators have played a major role in the recent blackout events.

Furthermore, that type of event is likely to recur in the future if adequate ageing programmes of the grids are not implemented, and if investments in modernising and constructing new distribution grids are insufficient.

Grid disturbances and loss of offsite power induce unnecessary challenges to nuclear power plant safety. They may result in deterioration of plant defence in-depth and as such, these events are considered as high risk-significance.

In light of recent developments in the opening of electricity markets to competition, the nuclear community should pay particular attention to issues related to electrical grid stability together with availability of power plant safety systems especially considering the ageing of distribution grids, as well as problems of communication between plant operators and grid operators.

2.2 Experience with fuel failures

Failures of fuel assemblies are the kind of event that occasionally occur in either the reactor or the fuel pool and because of diverse causes such as rod failures, fuel-design modifications, intrusion of foreign material, fuel-handling errors, etc. An example of fuel failures related to bad design of devices used during fuel maintenance activities is given by the event presented below.

Recently a nuclear power plant experienced a significant event with the failure of thirty fuel assemblies during the cleaning process performed into a cleaning tank. A cleaning device had been placed in the fuel pool and a number of assemblies inserted for the cleaning operation. After the cleaning process, the assemblies over-heated due to lack of sufficient cooling. Because of the non proven design of the cleaning device, the process led to over-heating and significant damage due to insufficient cooling flow.

Intrusions of foreign material into the primary system are also responsible for degradation of fuel assemblies. One example is briefly described below while other consequences and lessons learnt from foreign material intrusion in primary system are discussed in Section 2.3. At a pressurised water reactor plant, a severely damaged spiral-wound metallic gasket was found in a safety injection system check valve. A fuel failure was observed some months later. The fuel anti-debris devices were unable to catch some portions of the gasket, and the mechanical damage of the fuel cladding was likely caused by the pieces of the gasket that went through these anti-debris devices.

A new spiral gasket and a destroyed one found in the safety injection system check-valve (pen is shown to give the scale). *(Credit: Belgium)*

In another plant, two fuel assemblies were found to have failed at the end of the cycle. One element contained a rod broken in three parts while the other assembly had a leaking rod.

Finally, a plant reported on a deficiency in the fresh fuel transfer system, which had caused slight deformation of one of the endplates of fuel bundles. This deficiency had also resulted in loading of fuel bundles with deformed endplates in seven coolant channels.

Safety significance

Failures of fuel assemblies are safety significant because the fuel and its cladding represent the first fission product barrier. Failures first lead to contamination of primary coolant systems, and contamination of workers. However, more serious consequences may follow. For example, in the case of the first event, the cleaning process resulted in thermal shock and severe fuel damage and led to limited on-site release of fission products. Elevation of radiation levels was detected outside the plant limits during a very short period and slight contamination was noticed in the reactor hall. Despite limited actual consequences, this event presented potentially high risk of degradation for the fuel assemblies and higher consequences for the health of workers. Assuming that over-heating would have not been rapidly stopped, fuel assemblies would have been more extensively damaged and higher level of contamination could have been reached.

In the second event, in addition to potential contamination of reactor coolant systems, that type of degradation may lead to malfunctioning of control rods during an automatic shut down of the reactor because of potential loose parts coming from the failed fuel assemblies.

The third event represents a systematic failure source and a potential to multiple fuel failures at the same time.

Lessons learnt

Among lessons to be learnt from these events, one can mention:

i) Insufficient analysis by the contractor of the modification design, and the underestimation of the safety significance of the proposed design by both the licensee and the regulator, which led to a lack of rigorous review and assessment.
ii) Inadequate operating instructions and event recovery procedures.
iii) Potential malfunctioning of essential system for the control of the reactor power.
iv) Deficiencies in maintenance procedures and absence of post maintenance checks, which may result in foreign material intrusion.

> Failures of fuel assemblies, in addition to leading to long plant shutdowns and loss of electricity production, may have potential serious consequences in terms of contamination and nuclear safety. Any modification and operation regarding fuel assemblies must be subjected to rigorous and thorough risk analysis.

2.3 Experience with foreign material intrusion into the primary system

Intrusions of foreign material into the primary system have been reported to the IRS over the years. These events range from minor consequences on safety to major damages resulting in prolonged plant outages. During the reporting period, significant events involving foreign material intrusion confirmed that this issue is a recurring concern likely to lead to important consequences on both nuclear and personnel safety.

A significant foreign intrusion event was experienced at a pressurised water reactor when an operator misaligned one valve of the letdown and makeup system. That error resulted in the release of resin beads from the deboration demineraliser.

A second event in a boiling water reactor involved a failure of thermal sleeves in a tie-joint between the normal feed water system and the residual heat removal system. The sleeves worked loose and went to the feedwater divider header with some tiny parts even migrating into the reactor vessel.

Another possible consequence of foreign material intrusion is steam generator tube leak. Recent experience at a number of plants with thermally treated Alloy 600 or Alloy 690 tubing illustrates the need for thorough inspections and robust in-service inspection programs in order to alert to tube degradation regardless of the tube material, location, or steam generator history.

Safety significance

Consequences on safety include exposure and contamination of workers, obstruction of the sampling system, and a six-month outage of the facility for cleanup and repair. The potential consequences were substantial and included: loss of primary coolant (LOCA) due to reactor coolant pump seal failure; loss of high pressure injection pumps due to bearing failure; and partial unavailability of reactor scram due to stuck control rods.

Experience with leaks of steam generator tube indicates that damage by loose parts or damage incurred during manufacture of steam generator tubes can result in primary-to-secondary system leakage.

Lessons learnt

Among lessons learnt from these events, one can mention:

i) A non-fully-analysed modification with an impact on operating procedure, which led to an operator error.

ii) Flow-induced vibrations due to unproven design, lack of supervision and analysis.
iii) Lack of sufficient guidance and support for the project work including contractors and plant shutdown not done on a timely basis.

Experiences with primary-to-secondary leaks show the importance of being alert to all potential tube degradation mechanisms and to aggressively interrogate eddy current inspection signals that may be associated with tube degradation.

> Several IRS reports highlight that intrusion of foreign material into the primary system continues to occur despite changes in working methods and QA programmes. Such events, which range from minor consequences to major damages, deserve more oversight from both plant management and regulators.

2.4 Experience with piping degradations in secondary systems

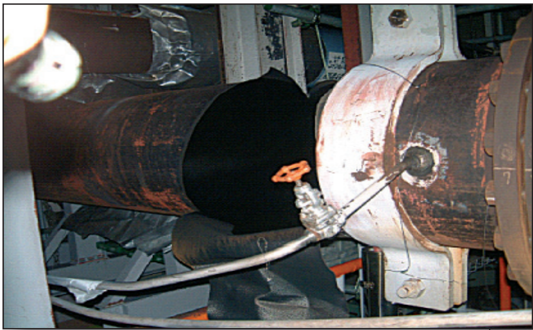
Piping degradations affect both the primary and secondary systems. Recently several events dealing with secondary systems have been reported to IRS. In several instances, in-service inspection revealed that initial piping wall thickness, had thinned to such an extent that in some cases it resulted in the sudden rupture of the pipe. There were also reports on cracks and leaks caused by thermal fatigue, which is a recurring phenomenon due to stratification, and mixing of hot and cold water.

During the reporting period, a significant event occurred at a pressurised water reactor that was in operation for almost 30 years. A rupture of the main condensate water pipe in the turbine building killed five workers and injured six of them. There had been several precursor events at similar plants over the period of about twenty years and a number of other erosion-corrosion events including pipe ruptures, have been reported to the IRS.

Another report, of generic nature, dealt with a review of industry efforts to manage thermal fatigue, flow-accelerated corrosion, and water hammer damages to sections of PWR feed water nozzles, piping and feed-rings.

Safety significance

Past failures of feedwater and other high-energy piping have resulted in complex challenges to operating plant when the released high-energy steam and water interacted with other systems. Personnel injuries and fatalities have also occurred. The failure to maintain high energy piping and components within allowable thickness values can adversely affect the operability, availability, reliability, or function of systems required for safe shutdown and accident mitigation; and/or impacts the integrity of fission product barriers. In addition, as shown by the above event, piping rupture may pose a significant threat for the safety of the workers.



Broken feedwater pipe.
(Credit: NISA)

Lessons learnt

While piping degradation mechanisms can be managed through careful and thorough analysis, inspection, monitoring, and mitigation and replacement techniques, several lessons can be learnt, among which:

i) Surveillance programme are not always rigorously applied or may not be adequate. In the above example, the ruptured portion of the piping had not been inspected since the plant start-up almost 30 years ago.
ii) Quality management of the contracted work by the operating organisation may be lacking.
iii) Oversight of this issue by safety authorities may not be sufficient to identify these deficiencies.

Industry guidance to predict onset and severity of the potential for wall thinnning may not be working properly, and the regulator oversight may be insufficient.

The piping degradation events remind all specialists involved in operating experience feedback of the absolute necessity and fully assess all precursor events, to implement timely corrective measures and lessons learnt from those precursors, and periodically assess their adequacy and completeness knowing the vast experience gathered on these phenomena.

2.5 Experience with reactor pressure vessel degradation

The previous issue of the Blue Book reported on a severe corrosion of a reactor pressure vessel (RPV) upper head of a pressurised water reactor (PWR). Other events as reported in the IRS have mentioned this sort of corrosion over the past 20 years, and thus this should be considered as a recurring event.

A recent event, although much less significant, involved the discovery of a minor amount of boric acid deposits around the lower vessel instrumentation penetrations at another PWR. Two penetrations exhibited cracks during the non-destructive examination. The defects affect the primary pressure boundary barrier. The largest of these cracks was entirely through-wall and extended above and below the J-groove weld.

Safety significance

The event, as discovered, had the potential for a very significant impact on safety because it could have led to a non-isolable leak of primary coolant. Based on the "as-found" condition of the penetration nozzles, it was however concluded that the risk was very low. Should the degradation mechanism(s) have induced large, circumferentially-oriented flaws in reactor pressure vessel lower head penetrations, the risk implications for the same type of reactors would be significant.

Lessons learnt

The regulator recognised that the inspections conducted by the licensee are superior to the ones recommended by the ASME code for the purpose of finding evidence of leakage like that observed at the concerned unit. Consequently, it is appropriate for licensees to assess their current inspection practices to ensure periodically that there are no leaks from RPV lower head penetrations. In addition, the existing regulatory requirements may need to be supplemented in order to ensure required inspections of RPV lower head penetrations are adequate to identify potential penetration leakage

> Several significant events have evidenced the corrosive impact of boric acid on ferritic steel. This aspect is of particular concern on reactor pressure vessel and primary coolant system. Strict compliance with regulatory requirements and application of adequate surveillance programmes on primary coolant equipment and system contribute to prevent occurrence of non-isolable primary coolant leak.

2.6 Experience with mid-loop operation

Several recent events illustrate the issue of loss of primary coolant while the Residual Heat Removal (RHR) is in operation. Despite the experience gained over the years on operation, non-routine operating modes still present non-negligible potential consequences, and need detailed safety analysis to prevent that type of event. That topic of generic nature is further discussed in more detail under the heading *3.1.1 Study on corrective actions related to loss of RHR at mid-loop*.

In one event, the reactor had been brought to cold shutdown for about 24 hours. The level in the primary circuit was being decreased when suddenly an uncontrolled and fast drainage of the reactor coolant system occurred. The inadvertent opening of two isolation valves in series, which separated the residual heat removal system (RHRS) from the refuelling water storage tank, caused the drainage. The control room operators were able to diagnose the direct cause and close one of the inadvertently opened valves, consequently avoiding air binding of the RHRS pumps and loss of reactor cooling.

In another example, while the reactor was shutdown, the reactor level dropped 10-15 cm below the lower extraction point for the reactor level measurement because of a misalignment of the reactor drainage line.

Safety significance

The first event resulted in a significant loss of primary coolant when the inventory of the primary system had already been reduced and the residual reactor heat was still considerable. Fortunately, a loss of the residual heat removal pumps – because of air binding – did not occur due to the timely response of the operating crew.

The second event had no consequence on safety because no loss of circulation occurred but only degradation. Consequences could have been more serious if the excessive draining of the reactor had not been stopped.

Lessons learnt

The first event shows that the inadvertent opening of the two isolation valves was the result of two consecutive errors committed during the execution of requalification tests of a plant modification in an electrical cabinet. The event investigation identified contributing causal factors related to:

i) The work preparation and planning of the requalification tests.
ii) Changes that affected the organisation of the test team.
iii) Deficiencies in the man machine interface that resulted from the requalification test.

In the second event, the excessive draining was caused by lack of operators' knowledge, inadequate experience with the behaviour of the core level measurement, inadequate documentation and error in procedures, and inadequate feedback from a similar event.

Even though many modifications have been implemented for more than twenty years in view of significantly reduce the risk against consequences of residual heat removal system failures, inadequate procedures, inadequate instrumentation and alarms, and wrong operator actions remain the main challenges to the resolution of that issue. Licensees and regulators should pursue their efforts to decrease further the frequency of this type of event.

2.7 Experience with essential service water system failures

The essential water system is required during all operation modes of light water reactors, including accident conditions, to supply cooling water to systems and components that are needed to operate the plant, to bring it to safe shutdown and to mitigate the consequences of an accident. During shutdowns, the essential service water system is also required to ensure the residual heat removal.

The IRS database contains a number of events related to failures of essential service water systems that resulted either in partial, or in some cases complete, loss of cooling of safety related equipment. That type of event is considered important in terms of risk because it challenges the availability of many plant safety-related systems at the same time.

During the reporting period, one event involving a circumferential break of an essential service water pipe occurred while the plant was at power. The cause of the break was corrosion at the outer surface of the steel pipe and inadequate surveillance programme. The plant was shut down and inspections further revealed corrosion on both trains of the system.

Another event involved one train of the essential cooling water (ECW) system, which suffered from a catastrophic piping failure, resulting in up to 12″ flooding of the turbine hall basement and 1″ flooding in the reactor building while the reactors were operating at nominal full load.

Safety significance

These events have an impact on at least two fundamental aspects in the design of nuclear power plant safety-related systems: the first aspect is the probability for common cause failure of redundant safety systems and the second aspect relates to interaction between safety systems and non safety-related systems and components.

Furthermore in the case of the second event, whilst no injuries resulted from this event, the potential for harm was significant.

Lessons learnt

Several lessons can be learnt from these events:

i) Large differences that exist between countries regarding the experience of essential service water systems operation have to be taken into consideration. However, many common phenomena have been noticed such as blockage of screens, pipe break or leakages, internal or external corrosion, extreme natural phenomena, silting.
ii) Reliability of essential service water system has to be treated on a plant specific basis given the large variety of differences in the design of the plants/systems.
iii) Adequate surveillance and maintenance programmes are essential concerning the availability of the systems.
iv) Inadequate procedures and operator actions constitute the main contributors for essential service water system failures.

> Reliability of essential service water system is regularly challenged by various causes. Inadequate procedures and operator actions constitute the main contributors to these failures. Their impact is significant on both potential common cause failures of redundant safety systems and interaction between safety and non-safety systems, which are not sufficiently covered in the original plant design.

2.8 Experience with uninterruptible power system failures

Several events involving a loss or failure of uninterruptible power system (UPS) have been reported to the IRS. As shown by the examples below, the safety of the reactor is in such cases challenged by the loss of safety related equipment and displays of essential information in the control room, and in particular the control of the core.

At one plant, discrepancies between the speed signal of the feedwater pump and the feedback signal of the reactor vessel water level caused an increase in the reactor water level and led to manually shutdown the reactor. The shift supervisor took a conservative decision assuming a failure of total rods insertion and declared an alert condition. It was found that the electronic devices in the UPS equipment that had been installed with a long term service had not been replaced within the specific times set by the vendors.

An event resulted in an unintended reactor power rise, due to the inoperability of a reactor power regulation system. The electricity supply to all the adjuster rods failed when the UPS supplying electricity to adjuster rods was being isolated for preventive maintenance.

Another event deals with a degradation of battery cells that have showed cracks in the cover. In some cases, these cracks have extended also in the vertical face causing leakage of electrolyte and consequently, a potential reduction of the battery cell capacity.

Safety significance

The first event had no actual consequence on safety since the reactor shutdown was successful. However the loss of UPS equipment leading to the loss of visual display in main control room of vital parameters such as reactor power and control rod position brings a potential risk for the normal and safe operation of the plant.

The second event revealed several inadequate appreciations of safety aspects of operation, which are indicative of degradation in the safety culture of the plant.

The safety significance of the third event deals with manufacturing and QA problems of all batteries manufactured from a given period in the same factory and a potential degradation of a safety function (loss of uninterruptible DC power).

Lessons learnt

Concerning the first event, the situation at the plant had already been detected during a technical inspection of the vendor some five years earlier. However, recommended corrective actions were not implemented because of deficiencies in the corrective action programme at the plant. After the event, all required changes in the procedures for maintenance of this type of equipment have been implemented in accordance with recommendations of the vendor.

In the second event the management systems pertaining to safety related matters and experience feed back were enforced notably for ensuring that design improvements are checked for their applicability to other units.

Regarding the batteries, the degradation of the epoxy resin was attributed to manufacturing errors. Stricter application of the QA manufacturer manual has been recommended and the manufacturing procedures have been revised consequently.

These events bring several lessons that have been mentioned earlier: those are notably, identified corrective action not implemented, deficiencies in manufacturing and QA processes, inadequate maintenance procedures, degradation of safety culture and deficiencies in management systems. All these aspects lead to breach the defence-in-depth and operate the plant under unsafe conditions.

2.9 Experience with fire-related events

Despite all measures taken during the design stage and the operation, fires may occur at nuclear power plants. Yet, because of the specific nature of nuclear power plants, consequences of an accident involving a fire may be aggravated in case of dispersion of contamination provoked by a fire. Large fires at a nuclear power plants are rare, but small fires take place more frequently and are a concern as regards the overall safety of the affected plant even though in most cases they are associated with the conventional systems of the plant (often the turbine).

Recently, a nuclear power plant was in start up phase after a refuelling outage. A fire occurred because of overheating in a wall penetration supporting 6.6 kV electrical cables routed between the electrical building and the turbine hall and powering the circulating water system pumps.

A plant reported an event involving smoke and fire signals received from a main circulating pump (MCP). The MCP was stopped and the fire extinguishing system was started. The fire was eliminated; however, the operation of the extinguisher system differed from that of the design basis.

Another event concerns a fire that broke out in the insulation of gland seal line in the turbine hall. The fire caused the turbine to be tripped manually and hence the reactor tripped automatically. The damage was limited to the insulation and production had to be stopped for five days.

In addition, significant numbers of false alarms have been experienced with fire and smoke detection systems and whilst these are a nuisance, they have the potential to densitise the operator to real alarms, should they occur.

Safety significance

These events have had no actual consequence on safety. However as shown by the first event, an electrical induced fire due to non-safety related cables might significantly affect the plant safety, even though fire is rapidly subdued. All those events challenged the safety of the plants because they caused unnecessary plant transients. In addition, as shown in the past, potential consequences of some fires were very serious.

Damaged insulation after fire on main circulating pump.
(Credit: HAEA)

Lessons learnt

The first incident has demonstrated the importance of separate trains, allowing the unit to be fallen back to a safe state using the remaining train available without major difficulties. Specific characteristics of the plant have to be taken into account at the design stage and risk analysis has to be carefully carried out when performing the safety analysis for a modification. Moreover, lessons are to be learnt from the absence of documentation on site concerning both the cable penetrations and the cables routed through them.

The second event shows that problems related to MCP oil leak were known to the power plant management for more than 10 years but corrective actions were not taken.

The third event revealed that weaknesses should be corrected in both the fire fighting training programme for every crew trained to deal with fires and the general maintenance of the turbine hall.

Fire-related events highlight the risk induced whenever plant specific characteristics are not considered at the design stage and risk analysis is not conducted as a part of the safety analysis for a modification. In addition, they remain the need to implement corrective actions without undue delay and to pay particular attention to fire fighting training programmes.

3. INSIGHTS FROM STUDIES, SPECIALIST MEETINGS AND WORKSHOPS

3.1 Generic studies

Generic studies (also called topical studies) are carried out on safety issues of general interest where there may have been similar topics in several of the participating countries. Generic studies are organised at the yearly meeting of the IRS coordinators or CNRA/WGOE and developed by consensus. A study usually takes two or three years to complete. The studies presented below were completed during this reporting period.

3.1.1 Recurring events and follow-up with corrective actions related to a recurring event: Loss of the residual heat removal system at mid-loop

As result of the 2002 international workshop co-sponsored by the NEA and WANO and the IAEA (see previous issue of the Nuclear Power Plant Operating Experience from the IAEA/NEA Incident Reporting System 1999-2002, and in 2003 a second report on recurring events was issued by the NEA Working Group on Operating Experience. It included the following recurring events: loss of RHR at mid-loop; BWR instability; PWR vessel head corrosion; hydrogen detonation in BWR piping; steam generator tube rupture; multiple valve failures in ECCS; loss of heat sink due to marine biofouling; system level failures due to human factors considerations and strainer clogging.

It is worth recalling the internationally agreed definition of recurring events:

"An event with actual or potential Safety significance that is the same or is very similar to important aspect(s) of a previous nuclear industry event(s), and has the same or similar cause(s) as the previous event(s).

Additionally, for an event to be considered as "recurring" there should exist prior operating experience with corrective actions either:

- Identified but not specified, or
- Not adequately specified, or
- Not implemented, or not implemented in a timely manner by the responsible organisation".

Lessons that have been learnt for those events encompass:

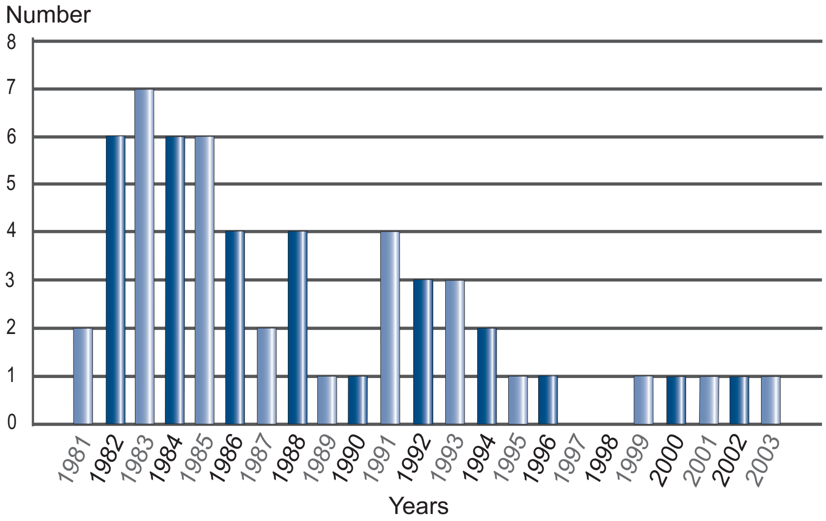
- The common factor of those classes of events is a long history of recurrence; analysis and evaluation of operating experience was generally weak.
- Events recurred for a variety of reasons.
- Regulatory action was not always decisive and prescriptive.
- Pressure to increase power production exists and, a more comprehensive analysis of member-state policies for corrective actions would be informative.
- International working groups have to communicate insights from the analysis of operating experience to government and industry bodies in order to improve the situation or at least not to let it develop to the worse direction.
- Modifications made in different countries based on operating experience feedback should be discussed during international meetings as done in the past.

In 2003, the CSNI/WGOE endorsed an extension of the recurring events work. The scope of the task was to review corrective actions that were applied to recurring events to determine the style and substance of corrective actions that seemed to be the most effective. In order to limit the scope, it was decided to select the loss of residual heat removal system while at mid-loop conditions for the detailed study of corrective actions. The main reasons were that:

i) These events have been taking place since the early eighties at a rate of about more than once per year over the past 20 years.
ii) Generally it is recognised that this type of event is of moderate to high risk significance.
iii) A number of countries have been involved, and the extent to which the regulatory authorities have issued binding corrective actions is not well-known to the international community.
iv) Finally the frequency does seem to have abated recently.

Between 1981 and 2004, there were approximately 60 mid-loop events, over about 3 600 PWR reactor-years, i.e. about 1 event per 60 reactor-years. This is a relatively high frequency for an event of dominant risk significance according to the low power and shutdown PSA studies. As the figure below shows, the recurrence rate is indeed diminishing, presumably as a result of numerous corrective actions implemented (7 events have been reported during the last ten years, as compared to more than 30 events reported during the eighties). Although some events are still occurring, responses from most member countries indicate that the issue is considered as resolved.

Frequency of mid-loop events



The range of corrective actions varied. In general, the options included installation of new and more accurate water level measurement devices, installations of core exit thermocouples, criteria and means for rapid closing of reactor coolant system and containment building, and application of improved procedures, and training programmes. As a specific example, the corrective actions implemented by one country in order to circumvent events of loss of residual heat removal system are as follows:

- automatic make-up;
- automatic shutdown of pumps draining cavity;
- vortex detector;
- improved instrumentation;
- changes in technical specifications;
- changes in outage organisation to forbid mid-loop conditions prior to core unloading.

A major outcome of the study is that corrective actions have succeeded in significantly lowering (although not altogether eliminating) the recurrence of mid-loop conditions. However, it has taken about 10 years to achieve a significant reduction in event frequency. While the first events were reported in 1981, and many events occurred in the next few years (more than 30) before some sort of regulatory guidance was available.

The report concludes that voluntary initiatives have not been very effective in eliminating the scenarios, while the mandatory solutions imposed by the regulator (or, in some cases, solutions jointly reached by the utility and regulator which are then converted into requirements) have been somewhat more effective in achieving the desired improvements.

> Safety managers and authorities might consider the extent to which an emerging problem, such as the mid-loop operation was twenty years ago have been given the appropriate attention for timely resolution of the issue. It is also of importance to consider the somewhat sparse nature of corrective actions that are described in the IRS reports. More improvements are needed here.

3.1.2 Modifications at nuclear power plants – Operating experience, safety significance and the role of human factors and organisation

Operating experience frequently shows that changes and modifications carried out at nuclear power plants may lead to safety-significant events. At the same time, modifications are necessary to ensure a safe and economic functioning of nuclear power plants. Both licensees and regulators must bring proper attention to the processes for change and modification to ensure the continuing safety of nuclear power plants.

Experts from the industry, regulators, and technical support organisations from 15 countries met in Paris in October 2003 to exchange their views on these issues and to make recommendations.

The main outcomes of the workshop are summarised below:

- Modifications at the nuclear power plants significantly affect the operation and/or maintenance of the installation. A modified system may be more complex from the personnel point of view than a very new one. It is a good practise to perform a general review of the modifications implemented at least on a 10-year interval.
- Awareness should be raised on deficiencies in the modification process which may contribute to events regardless of the size of the modification project or its object.
- Events related to minor or non-identified modifications (MiNIMs) have shown to reduce the availability and reliability of equipment that is important to safety. MINIMs may generate common cause failures influencing multiple layers of safety barriers. It is very important to subject even small modifications to proper identification, analysis and testing.
- Changes and modifications should be subject to a careful screening at an early point in the modification process and should encompass both technical and human factors considerations.

- Temporary modifications are another class of modification that requires attention, because they are often not subjected to an in-depth safety analysis. A good practice is to restrict any temporary modification to a maximum duration.
- It would be beneficial if regulators from different countries could create a harmonised view on requirements to be placed on acceptable modification processes.
- Personnel competency should be addressed in a broader context to ensure that important knowledge connected to the plant design basis is not lost when turnover happens.

Additional international work might focus on increasing awareness and understanding of the problems that modifications could cause to the plant personnel if they are not given proper attention. Such work could concentrate on collecting experience from actual modification projects and from events following modifications to create better guidance for the nuclear utilities and regulators.

A special topic of the work was minor modifications (MINIMs). Examples of non-identified modifications have emerges with spare parts slightly modified by the manufacturer without informing the plant. They may also occur if materials in components (such as cables, lubricants or seals) are changed without proper notification to the plant. Events have demonstrated that there have been small changes between products series that the manufacturer did not recognised. If the plant is not aware of a modification, it will evidently not initiate an impact assessment and may thus lead to unexpected behaviour, which is difficult to diagnose.

Non-identified modification may also be introduced by maintenance activities in the following situations: (i) spare parts are not fulfilling required specifications due to wrong storage conditions; (ii) human errors occur during installation due to unclear labelling of components or spare parts; and (iii) quality assurance procedures are inadequate. They may even generate common cause failures influencing multiple layers of safety barriers. Such failures may remain undetected, as operating experience shows, especially when the anomalies are difficult to identify by pre-operational or periodic tests.

There is also the possibility that several small changes may have a major impact on some important parameters. This has been seen in the development of fuel characteristics where gradual developments over the years resulted in the combined effect that one of the fuel feedback coefficients could move in an unfavourable region during certain plant transients. A similar problem is that cumulative effects of minor changes may be significant, but an overall integrated analysis has not been carried out, as each minor change is, in itself, insignificant and may be implemented at widely spaced time intervals.

> Plant personnel, manufacturers, and contractors must be sensitized to small changes in components and materials. Minor and temporary changes present their own challenges for the nuclear power plants. While regulators and their technical supports have neither the capability nor the role to know all about the modifications implemented either by the plant operator or by a manufacturer, they must be sure that utilities remain responsible for the safety management of all modifications.

3.1.3 Analysis of cracking and corrosion in passive components of the primary reactor coolant pressure boundary

Evaluation of the effects of material degradation on the failures of passive components associated with the primary reactor systems are presented in a recent topical study based on data where cracking and corrosion resulted in cracks, leaks, breaks, ruptures, and weld failures. The source of the information is primarily from the records in the IRS database, but some public records from the United States experience have been added. This topical study has focused on cracking and corrosion issues leading to primary reactor coolant failure and degradation, the root causes, and the lessons to be learnt from the operating experience.

The IRS database shows that the predominant cause of failure mechanism is primary-water stress corrosion cracking (PWSCC). In particular, PWSCC of Alloy 600 steam generator tubes is a widespread problem in both once-through and recirculating steam generators around the world. Earliest examples of PWSCC in components other than the steam generator tubes have been in the base metal of instrument nozzles and heater thermal sleeves in the pressuriser. The other major examples of PWSCC are the penetrations for control rod drive mechanisms (CRDM) in the reactor pressure vessel heads.

In all cases, the root causes of PWSCC are:

- use of a susceptible material such as Alloy 600 or its weld filler metals, Alloy 82 and 182;
- presence of residual stresses from welding or cold work;
- contact with PWR primary water.

The standard corrective action is replacement of the susceptible Alloy 600 and Alloy 82 or 182 materials with the more resistant Alloy 690 base metal and Alloy 52 or 152 weld metals. Of the various forms of SCC of nuclear reactor components other than PWSCC, the most prominent, particularly in the 1970s and 1980s, has been the oxygen-assisted intergranular stress corrosion cracking (IGSCC) of BWR stainless steel reactor coolant system piping. The examples of SCC described in the study underscore several aspects:

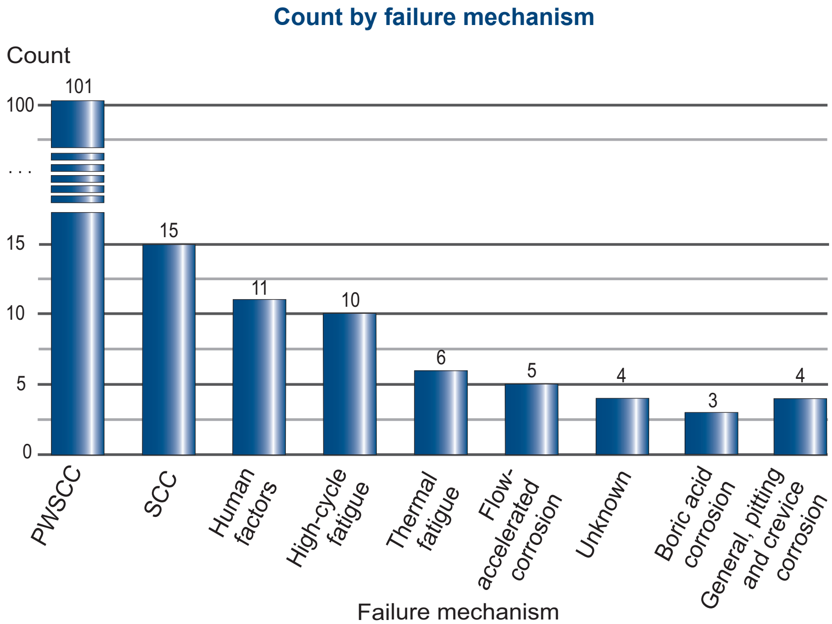
a) Oxygen-assisted IGSCC of BWR reactor coolant circuit piping and related components was a significant problem in the 1970s and 1980s, but the use of more resistant piping materials (e.g., Type 316 NG SS) and improved fabrication procedures to reduce residual stresses have largely solved this problem.
b) Chloride-induced transgranular stress corrosion cracking (TGSCC) associated with the inadvertent introduction of chloride contaminants continues to be a sporadic problem.
c) Irradiation-assisted SCC is confined almost entirely to reactor internal components exposed to high radiation fields.

Among other failure mechanisms numerous examples of high-cycle fatigue failures of nuclear components are discussed in the topical study. In nuclear power plants, high-cycle fatigue most commonly occurs as a result of vibrational loading, typically mechanical or flow-induced. These fatigue failures can be attributed to poor design, construction, or support structures. Often anomalies are detected at pipe support or anti-whip devices. Several measures can be useful to prevent failures caused by high-cycle mechanical fatigue. Conditions such as damaged support or blocked snubbers that can add to mechanical fatigue should be checked periodically.

The study states that the IRS database includes a comprehensive generic discussion of the phenomenon of thermal fatigue of coolant boundary components. It is recalled that thermal fatigue is a progressive failure mechanism brought about by prolonged exposure to cyclic loading associated with repeated temperature cycles and the resulting cyclic thermal stresses. In the large majority of the reported failures, thermal fatigue is associated with thermal stratification and striping. As implied by the IRS reports, these are plant design and operating issues rather than materials-related problems. Prevention of thermal fatigue depends upon improved plant design and operation rather than better materials selection.

Several instances of flow-accelerated corrosion (FAC), also known as flow-assisted corrosion or erosion-corrosion, have been reported to IRS. FAC is more likely to occur in carbon and low-alloy steels than in stainless steels. Such failures are most commonly found at locations of high flow rate, such as in the feedwater and turbine steam piping. Thus, FAC can be minimised both through the proper selection of materials as well as proper design in high-flow rate regions. However, the continuing occurrence of this failure phenomenon also underscores the importance of wall thinning management programmes to detect regions of wall thinning and incipient failure.

Wastage of carbon steel and low alloy steel due to boric acid corrosion has been observed in PWRs for at least 30 years. The IRS database lists several examples of this kind of corrosion. These examples point up the potential for boric acid corrosion of ferritic steel components in PWRs, particularly closure bolts and studs. Less commonly, but more significantly, a specific incident, which involved a pressure head vessel cover illustrates the potential for severe damage to major pressure boundary components, when uncorrected, primary system leakage results in prolonged exposure to boric acid deposits. Control of boric acid corrosion is largely an operational problem and requires prompt detection and correction of primary system leakage.



In general, pitting, and crevice corrosion were also of serious concern as failure mechanisms reported to IRS and analysed in this topical study. Both uniform and localised corrosion remain an aging issue but seem to be managed more effectively than cracking.

Of the various forms of SCC of nuclear reactor components the topical study underscores the fact that most of the causes are related to plant design and operational issues, poor design, construction, or support structures. While some of these failures are considered resolved, the continuing occurrence of some of these failure phenomena also underscores the importance of preventive measures based on improved plant design and operation, in-service inspections to detect affected regions, prompt detection and correction of primary coolant leakage.

3.1.4 Closing the feedback loop from events to definite elimination of the causes

It is largely recognised that the IRS plays an essential role in ensuring proper reporting of safety-significant events and disseminating widely the lessons learnt, which help to reduce the frequency and severity of safety-significant events at nuclear power plants. However, in 2003 several recurring events and other already known problems led the national IRS coordinators to initiate a study aiming at "how to better close the operating experience feedback loop".

That study is intended to identify how the information is disseminated, to highlight good practices in the operating experience systems, to identify weak points in both the dissemination and the use of the information in participating countries, and to propose ways to improve the efficiency of the operational experience (OPEX) feedback process.

Among identified good practices, it was noticed:

i) During the design review of a nuclear power plant prior to awarding the authorisation for commissioning activities, some countries make mandatory for submission a section on OPEX as part of preliminary safety assessment report.
ii) Most regulatory bodies receive periodical report (quarterly in general) on OPEX from nuclear power plants, which includes events reports, specifically lessons learnt and corrective action taken.
iii) Some regulatory bodies issue letters from lessons learnt from events and other OPEX inputs. Some also indicate the expected actions from the licensee.
iv) Several countries have set up special cell both at the national IRS coordinator's office and at the utility HQ for processing inputs from OPEX, including IRS events, WANO, various operator's group.

There are also useful complementary tools that can be combined with the operating experience feedback process to help in eliminating the causes of events and achieving safe operation. These are a) instituting a system for learning from low level events, precursors, near misses, deviations etc., b) use of PSA, c) use of periodic safety review, d) features in design, operation, maintenance and management etc., e) reliable commissioning. All these can be reviewed by Member States for appropriately incorporating them in their systems, practices and procedures.

Some points have been identified that may need additional efforts from the international community as well as Member States for better closing the feedback loop. In particular, a methodology could be worked out to share experience about the reporting systems of low-level event/deviation/near misses/precursors that many countries have implemented. A greater use of the results of topical IRS studies would be extremely beneficial to the nuclear community.

3.1.5 International Common-cause Data Exchange (ICDE) Project

Events initiated by common-cause failure (CCF) can significantly affect the availability and reliability of nuclear power plant safety systems. In recognition of this, CCF data are systematically collected and analysed in several countries. A serious obstacle to the use of national qualitative and quantitative data collections by other countries is that the criteria and interpretations applied in the collection and analysis of events and data differ. A further impediment is that description of reported events and their root causes, which are important to the assessment of the events, are usually written in the native language of the countries where the events were observed and not in all cases reported to IRS. To overcome these obstacles, the preparation for the International Common-cause Data Exchange (ICDE) Project was initiated in August of 1994. Since April 1998, the NEA has formally operated the project to which eleven countries participate.

Data analysis and exchange covers for the time being the following components: centrifugal pumps; diesel generators; motor-operated valves; safety and relief valves; check valves; reactor protection system components (level measurement, control rod drives, etc); circuit breakers, and batteries. The ICDE collects all events where two or more identical, redundant components fulfilling the same function have failed, or are impaired due to a shared cause. A subset of these are complete CCFs, i.e. all of the identical, redundant components in the group have failed due to a shared cause.

Number of reported ICDE events and ICDE events with complete CCF component

Component	ICDE Events	Complete CCF	Per cent
Centrifugal pumps	222	41	18.4
Emergency diesel generators	148	28	18.9
Motor-operated valves	100	5	5.0
Safety and relief valves	192	22	11.5
Check valves	105	9	8.6
Batteries	57	3	5.3
Breakers	107	6	5.6
Level measurement	146	5	3.4
Total	**1 077**	**119**	**11.0**

The main outcome from the reports issued by 2005 shows that for all components, about two thirds of all complete CCF events involve faulty actions by plant personnel and contractors. The role of human action also increases with the number of redundant components. The single largest contribution is from faulty testing and maintenance work due to deficient and/or incomplete procedures. Another cause is from insufficient work control.

The probability that a reported ICDE event (i.e. event including some degree of dependence) is a complete CCF decreases strongly with increasing number of redundant components, demonstrating the effectiveness of redundancy as a good defence against CCFs. However, complete CCFs cannot be completely prevented by high redundancy only.

Deficiency and incompleteness of procedures together with insufficient work control and operator error of commission are shown to be the most frequent causes for complete CCFs. Faulty human actions and organisational problems like deficient documentation and communication are important causes for complete CCF especially during re-qualification (i.e., restoration and re-alignment of systems to operation): Valves and electrical equipment were identified as particularly vulnerable to requalification problems.

Most of the events leading to complete failure involve human actions. They could be corrected by better procedures and control/maintenance practices. Main areas for improvement against CCFs according to ICDE project are the following: 1) scrutinising existing operation, maintenance and testing procedures for deficiencies creating the potential for CCF of redundant systems, 2) ensuring comprehensive work control, 3) comprehensively prescribing the steps of testing required in the requalification of components or systems after maintenance, repair, modification or backfitting work, and 4) intensifying personnel awareness of CCFs, pre-job briefings, introducing ergonomically better designs and introducing more key locks.

3.2 Specialist meetings and workshops

3.2.1 Debris impact on emergency coolant recirculation (strainer clogging issue)

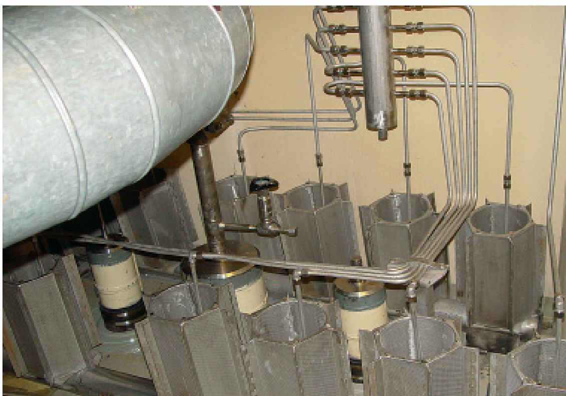
In 1992, a steam line safety relief valve in a boiling nuclear water reactor inadvertently opened. One consequence was that debris was dislodged and transported into the suppression pool, and this resulted in clogging of strainers on the suction side of various pumps. This attracted international concern.

Although the incident in itself was not very serious, it revealed a weakness in the defence-in-depth concept which under other circumstances could have led to the emergency core cooling system (ECCS) failing to provide recirculation water to the core. Research and development efforts were launched and resulted in substantial backfittings being carried out for boiling water reactors and to a lesser extent to some pressurised water reactors over a number of years.

In 1998, the international community decided to revisit the subject with the specific objective to review the latest phenomena for pressurised water reactors and to provide a survey of actions taken in member countries.

In 2004, a workshop was organised to discuss the impact of new information made available and to promote consensus among Member States on identification of remaining technical issues important to safety, and on possible paths for their resolution. The discussions led to the following main findings:

- The safety significance of the sump strainer clogging depends on the plant design (e.g. sump strainer, emergency core cooling systems) and backfitting measures performed.
- Design features of pressurised water reactors that could influence the impact of debris on sump strainer performance encompass:
  - type of insulation (material, combination of materials, protection);
  - break size to be postulated;
  - transport in containment with or without containment spray system (CSS);
  - degree of turbulence and flow velocities in the sump influenced by CSS, water level, break flow location and sump geometry;
  - redundancy of sumps and residual heat removal system (RHRS);
  - strainer design (area, mesh size);
  - positioning of recirculation pumps and vortex protection;
  - amount of latent debris (e.g. use of qualified coatings, size of unprotected ferritic surfaces, cleanliness regime after outages);
  - chemical effects due to NaOH.
- Sump strainer clogging may substantially increase the total core damage frequency depending on the design features mentioned above and the assumption made to estimate the amount of insulation material reaching the sump strainer and the resulting pressure loss.
- Rapid resolution of the sump strainer clogging issue is essential. Some participants presented solutions to the problem based on new strainer designs, reduction of insulation material generation and development of strainer cleaning procedures (e.g. back-flushing).
- Assessment methods should continue to be enhanced.



Modified sump strainer.
(Credit: STUK)

Sump strainer clogging may substantially increase the total core damage frequency. Research efforts should be agressively pursued so as to accelerate the resolution of the sump strainer clogging issue.

3.2.2 *Events including contractor and sub-contractor influence*

In the recent past years, regulatory bodies and industry representatives expressed a common concern regarding the ongoing gradual loss of experienced and competent personnel in nuclear technology and the resulting weakening of nuclear field organisations. Events involving contracting organisations are regularly reported since the beginning of the IRS database back in 1980 despite many changes in plant organisation and in regulatory measures implemented over more than twenty years.

International working groups discussed this issue in 2003 and 2004 and an international forum was held in 2004. Main lessons learnt from the IRS reports and discussion among experts, encompass:

- Events directly or indirectly attributed to contracted workers affect a large spectrum of components and systems. Their consequences on safety range from minor deficiencies up to the loss of safety functions, contamination and injuries of workers.
- Contracted work is more prone to error in cases where specific competence is required by the nuclear industry.
- In several instances, problems observed were not really specific for contractors but could also be attributed to licensee's organisation: delegation of responsibility to the contractors, insufficient assessment of the contractors' competence, insufficient oversight by the licensees of the contractors' work.
- The lack of supervision of the contracted work by the licensees was quite often associated with insufficient or incomplete documentation or deficiencies in their QA programmes.
- Licensees have to demonstrate their capability to be intelligent customers, and how they define resources and means regarding core competencies, staff needed, organisation & management of the work.
- Licensees have to qualify contractors but as shown in several instances, the formal QA qualifying procedure may not be always sufficient.
- Licensees have to oversight that the contracted personnel has the sufficient safety knowledge notably by more and better training on nuclear requirements and NPP specific arrangements.
- Lack of regulatory oversight in licensing and inspection, stress of time and overemphasis of production versus safety are among contributing factors found in IRS reports.

- Regulators should have a policy to make sure that the licensee and the contractors are technically qualified to construct and operate the facility throughout the lifetime of the installation;
- Licensees and regulators should consider the possible loss of knowledge due to merging of companies, the risk of disappearance of internal global oversight and overall plant safety ownership.

From the discussions, experts from licensees and regulators concluded that:

- Licensees need to develop strategies for dealing with diversified contractors who are becoming more global and grow in size whereas their organisations remain more or less the same – this may be a special problem for small countries;
- Regulators needs to develop their practices for verifying adequate arrangements between licensees and contractors;
- Licensees need to improve their own knowledge in order to conduct more technical work in-house or to become more intelligent customers;
- Certain core tasks cannot be outsourced. They must be conducted by the licensee staff (international guidance is needed on what are those tasks);
- Contracting work is not a threat to safety but management of the tasks on-site must remain in the hands of licensee.

Regulators may need to consider whether their regulatory and legislative framework remains the best for ensuring safety if the structure of the industry changes significantly, such as am increased reliance on contractors, and the move from operational to de-commissioning sites.

> Regulators and licensees should give proper attention to the possible loss of knowledge due to merging of companies, outsourcing, and the risk of disappearance of internal global oversight and overall responsibility for safety.

3.2.3 Safety performance indicators: Observations on operating reactor safety and efficiency performance

Regulatory Bodies are monitoring closely the performance of nuclear power plants as for most safety significant parameters, such as scrams or collective dose. They need, in addition to inspection results, indicators to evaluate the safety of the installations. Many indicators are based on licensee event reports of which the most important ones are reported to IRS. Harmonising and sharing good Safety Performance Indicators (SPI) practices help nuclear regulators to fulfil their role.

In some countries, a growing demand exists for information about performance of nuclear power plants from stakeholders such as policy makers, parliament, public, and media. Such a demand has to be responded to and the provided information needs to be meaningful and understandable. Moreover, new regulatory practices such as moving towards risk informed regulation emphasise the role of quantitative information and risk-informed indicators.

In 2004, representatives from 18 countries participated in a workshop to share their views and experiences in the area of development and use of SPIs. The general observation is that all participating regulatory bodies use or intend to use safety performance indicators (SPIs) in one way or another in their regulatory oversight. Typically, the areas covered by SPIs are: reactor safety; radiation safety; emergency preparedness and human and organisational performance. The availability of the SPI system to the large public varies from country to country.

There is a quite large consensus on the fact that SPIs are a tool to aid in decision making among other complementary sources of information on licensees' safety performance. Therefore, building indicator systems is not in itself an objective. Rather, the indicator system should be constructed so that indicators would provide decision makers with as much good quality information as possible for a variety of safety related decision-making situations.

Thus, the needs of each regulatory body will determine the scheme of SPIs it will use. Some regulatory bodies have established a formal and public SPI system with thresholds launching regulatory actions. Most other countries have a system where indicators are used in combination with other regulatory activities, e.g. inspection results and regulatory decisions are based on the synthesis of available data.

Ideas to build exclusive indicator systems, and to manage safety entirely by using only those with tools like PSA, have led some countries to fear that such systems would lead to tunnel vision. This would mean managing indicators, i.e. only attempting to minimise or maximise their values, and forgetting other contributors to safety thus "managing indicators and not safety". From the discussions of the workshop, it seems that countries that have experience with indicators are learning to overcome this problem.

The workshop participants reported many examples of misunderstandings with how indicators should be calculated or measured. Therefore, irrespective of whether the regulatory SPI system is formal or not, the definitions and the aims of SPIs need to be documented carefully.

"SPIs do not tell you the truth,
they only tell you where to ask questions."

Participants agreed that a “universal comparative SPI set” would not be relevant and that extreme caution is required when SPIs are compared.

Although there was no agreement about what the indicators of safety management and especially safety culture are or could be, participants agreed that looking for indicators for human and organisational performance and safety management effectiveness is indispensable.

Both licensees and regulators recognise the risk that performance indicators can become self serving, and warn against servicing the performance indicator (and targets) rather that the intent of the indicator, that is to measure and hence improve nuclear safety.

4. CONCLUSIONS

One of the essential elements of operational safety is the operating experience feedback processes that take place at both national and international levels. The incident reporting system is one link of the chain. In providing the world safety experts and managers with information on individual and generic issues of safety significance, the IRS together with other reporting systems, contributes to prioritise issues important to safety and assists in the identification of areas where further resources or research is appropriate.

This third edition of *Nuclear Power Plant Operating Experiences from the IAEA/NEA Incident Reporting System, 2002-2005*, intends to highlight important lessons learnt from events reported to the IRS over that period and to provide senior safety managers and staff members as well from regulatory bodies and in industry with information related to the safety of nuclear power plants to help them in their decision-making role.

About 200 events have been reported by the participating countries during that period and several among them as well as generic issues were selected in this report to show the range of important topics reviewed during that period by the national IRS co-ordinators.

Almost all of the events reported during that period have already occurred earlier in one form or another. It shows that despite the existing exchange mechanisms in place at both national and international levels, corrective measures, which are generally well-known, may not reach all the end-users, or are not always rigorously or timely applied. These events also reveal a deficiency in the operating experience feedback loop and therefore require closer examination from both regulators and utilities.

Examples of events and results of generic studies demonstrate the usefulness of the exchange of experiences and their contribution to reduce the risk and consequences associated with long-standing generic issues affecting power reactors.

Good practices and strong points in the operational experience process that could be reviewed for adaptation by Member States were also discussed. In parallel, several weak points have been identified that may need additional efforts from the IRS community as well as Member States for better closing the feedback loop.

Recently, some top regulators expressed their concerns with respect to the international effort devoted to operational experience. They notably noticed that:

- A worldwide observation is that operating experience feedback (OEF) needs to be much improved in the international arena.
- There is a tendency to consider that foreign OEF is not relevant.
- The global effort in the area of event reporting does not appear to be functioning as it should.
- The focus of existing networks (IRS, etc.) should move from event reporting towards a synthesis of the given information and to combining it with other available knowledge on the respective topic, e.g. insights from risk studies and other research.

These remarks deserve to be carefully considered by all actors involved in OEF activities. Operating experience remains essential for improving methods and data used in safety assessments and defining priorities in additional research and regulatory responses to safety issues. Exchange of operational experiences is a lively process that requires strong involvement of all experts involved in that area in order to maintain and improve safety in the long term in the most efficient and effective way.

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APPENDIX

The Beginning of the Incident Reporting System

Excerpts from the Steering Committee for Nuclear Energy meeting
OECD, Paris, 19 October 1978

Proposal for a CSNI system for the exchange of information on operating experience in light water reactors (by the Unites States)

1. The use of operating experience as feedback to the nuclear energy has two immediate and obvious benefits. First is the use of operating experience to enhance safety. Clearly, safety is an international commodity which must be shared by everyone. The second is use od operating experience to improve overall plant availability and reliability. Such feedback will have an added benefit since a more reliable plant is likely to be a safer plant.

2. It is difficult to establish general principle as to what kind of operating experience serve each of these to interlocking purposes; but, it does appear that operating experience that has near-term safety impact represents a comparatively small data base. In contrast, the information needed to improve overall plant availability and reliability involves a very large data base. The safety significance of each individual unit of such data is quite small or not applicable. These two uses anf type of data suggest the possibility of different mechanisms of collection, evaluation, and discussion or dissemination.

3. The need to make available important safety information is a recognised feature of the bilateral agreements between the United States and 16 other countries. The format for such information consists of an exchange of letters and various reports as they become available, as well as periodic meetings with representatives of regulatory agencies of the member countries. This form of exchange of information is useful and exemplary exchanges could be cited. They have been mentioned in previous discussions.

4. The question does arise as to the completeness of this information exchange and whether multilateral agreements need to be considered to assure wider spread availability. It is suggested that CSNI studies how to proceed with enhancing safety information exchange from operating reactors. For this purpose it is propose that CSNI set up a Working Group to examine the matter and report its findings to the next meeting of the Committee. In doing this the Working Group should take into consideration other regional reporting schemes, for example that of the Commission of the European Communities. CSNI would need to consider not only the timely availability of the information, but also a mechanism to assure dissemination and follow-up.

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