Nuclear Power Plant Operating Experiences

from the IAEA / NEA Incident Reporting System 1999 – 2002

JOINTLY PREPARED BY IAEA AND OECD/NEA

IAEA
International Atomic Energy Agency

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INTERNATIONAL ATOMIC ENERGY AGENCY

The International Atomic Energy Agency (IAEA) serves as the world's foremost intergovernmental forum for scientific and technical co-operation in the peaceful use of nuclear technology. Established as an autonomous organization 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 134 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 tackl 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 Organization (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.

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

- to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
- to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
- to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995), Hungary (7th May 1996), Poland (22nd November 1996), Korea (12th December 1996) and the Slovak Republic (14th December 2000). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of the OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full Member. NEA membership today consists of 27 OECD Member countries: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Portugal, Republic of Korea, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The Commission of the European Communities also takes part in the work of the Agency.

The mission of the NEA is:

- to assist its Member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as
- to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

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.

IAEA/NEA INCIDENT REPORTING SYSTEM (IRS)

IRS

Feedback from safety related operating experience for nuclear power plants

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 learned about safety.

The Incident Reporting System (IRS) is an essential element of the system for feeding back international operating experience for nuclear power plants. IRS reports contain information on events of Safety significance with important lessons learned. These experiences assist in reducing or eliminating 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). *It is important that sufficient national resources be allocated to enable timely and high quality reporting of events important to safety, and to share these events in the IRS database.*

The first report, which covered the period July 1996 – June 1999, was widely acclaimed and encouraged both agencies to prepare this second report in order to highlight important lessons learned from around 300 events reported to the IRS for the period July 1999 – December 2002. Several areas were selected in this report to show the range of important topics available in the IRS. These include different types of failure in a variety of plant systems, as well as human performance considerations.

This report is primarily aimed at senior officials in industry and government who have decision-making roles in the nuclear power industry.

CONTENTS

1. DECISION MAKERS AND THEIR USE OF THE IRS

1.1 How can the IRS benefit the decision makers?

Decision makers in the industry, regulatory bodies and nuclear organisations around the world face a new challenging environment of deregulation, privatisation, economic pressures and fierce competition in the market place. This new environment forces decision makers to seek new strategies and manage risks and resources with the objective of achieving, among other things, the ultimate common goal of safety. The Incident Reporting System IRS plays a role in this regard by providing information on safety-significant events from the global nuclear community.

In managing risks and resources, decision makers need credible and reliable information on their managed systems, in particular areas of high risk, in order to prioritise their programs accordingly. They need to get 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 learned with others, thus making efficient use of their resources.

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 that address actual or potential hazards in a manner limiting the risk to the public.

Decision makers in the industry or regulatory bodies need to see the big picture. 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 analysis methods.

The IRS is one of the tools which can be used to serve current and future needs of decision makers. It can provide the world experts with information on individual and generic issues of Safety significance, and advance information on deterioriating safety performance. The IRS can also be used, together with other databases, to prioritise those issues of Safety significance which 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 learned from events which have been reported.

1.2 The establishment of the IRS

The IRS, which has been established more than 20 years ago, is now 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 IAEA.

The IRS as a worldwide system is designed to complement national schemes. It ensures proper reporting and feedback of safety significant events in the nuclear power plants for the international community, so that the causes and lessons learned may be disseminated widely. In this way, the IRS plays a role in prevention of the occurrence or recurrence of serious incidents or accidents.

The need for such an international system 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 analyze 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 organizations and regulatory bodies".*

Countries participating in the IRS

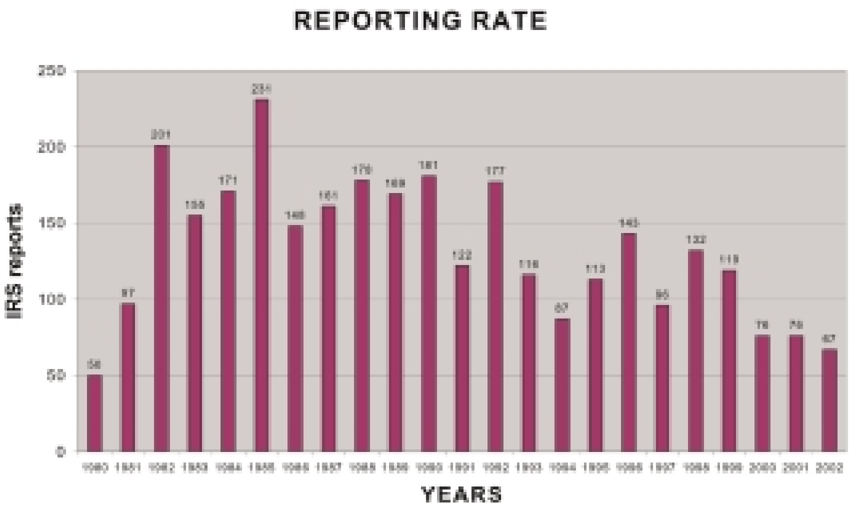
Argentina	Lithuania
Armenia	Mexico
Belgium	Netherlands
Brazil	Pakistan
Bulgaria	Romania
Canada	Russian Federation
China	Slovakia
Czech Republic	Slovenia
Finland	South Africa
France	Spain
Germany	Sweden
Hungary	Switzerland
India	Ukraine
Italy	United Kingdom
Japan	United States of America
Korea, Republic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

Activities within the IRS extend beyond the exchange and feedback of event information. Both the NEA and the IAEA have assigned working groups of experts who meet annually and discuss the safety relevance of such events. These groups take part in in-depth discussion of recent important events. Conclusions and recommendations from in-depth discussions are extremely valuable to the nuclear community in helping to enhance the safety of plants in the design and development stage and in operation.

1.3 Reporting to the IRS

Reporting to the IRS is based on the voluntary commitment of the participating countries. 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 learned.

Currently, the IRS contains more than 3000 reports gathered from the participating countries over the past 23 years. The annual reporting rate since 1980 is shown in the graph.



At present, less than 80 events are reported per year, from a family of about 500 reactors. Although the general quality of the reports exchanged through the IRS has improved, the reporting rate has generally declined over the past 15 years, in particular over the last three years. It is likely that the number of reportable events within each member state has decreased over this time period, and this would in turn contribute to a decline in IRS reports. However, another reason could be the lack of resources available in some member states. The decision makers' role in allocating appropriate resources to the IRS event reporting, within their own organizations is, therefore, important in maintaining the safety benefits that all Member States share.

1.4 Data storage and retrieval

The reported data is maintained in an enhanced 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 constantly updated and sent to the national IRS co-ordinators by the IAEA on a quarterly basis. Currently, efforts are underway to develop a web-based IRS that will be made available to the participating countries through their IRS co-ordinators around the world.

2. EVENTS AND EXPERIENCE GAINED

2.1 Experience with severe corrosion of the reactor vessel upper head

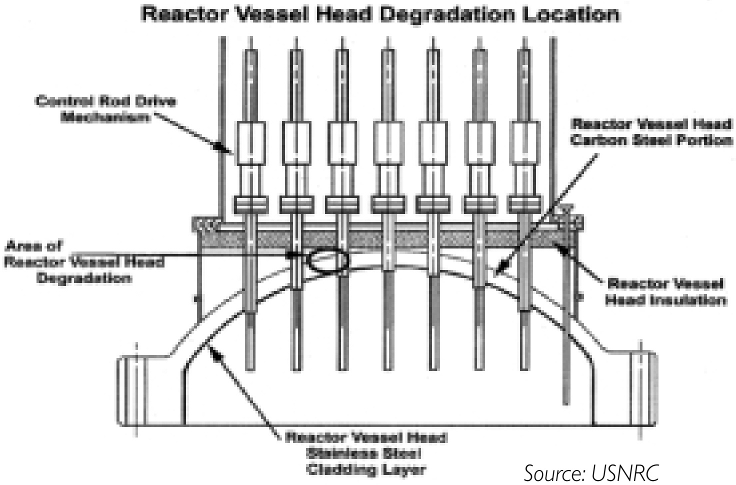
The reactor pressure vessel has a removable upper head that is bolted to the reactor vessel during normal operation. The inner surface of the carbon steel vessel is clad with a thin layer of stainless steel for corrosion protection. During normal operation the internal pressure is on the order of 150 bars (for a Pressurized Water Reactor, which is the subject of this reportable condition). Boric acid is a normal component of the pressurized water coolant, as described in the box below.

Summary of the reported event

The operator of a pressurized water reactor discovered, in response to a directive from the regulatory authority, a significant cavity in the reactor upper head, in the area shown on the figure below. This examination was prompted by defects in this general area that had been discovered by other plant operators in various member states. Boric acid leaked onto the outside of the vessel head and, over time, corroded essentially completely through the 6.5-inch steel, such that the only pressure-retaining metal was the stainless steel clad material.

> Boric acid is added to the primary coolant to absorb neutrons during the operating cycle. It is gradually removed, by a purification system, to compensate for the fuel burnup. Near the end of a cycle of plant operation the boron concentration is reduced to nearly zero. At the range of concentrations normally in the system, the corrosive effect is very small.

Apparently this corrosion had been active for several years before discovery during this event.



Source: USNRC

Safety significance

If the corrosion had further proceeded to the point that the stainless steel cladding could no longer provide pressure boundary integrity, then the cladding would fail and there would be a resulting loss of coolant accident. Conventional safety analyses do not cover this event, as the requirements for calculating the consequences of a loss of coolant accident apply to failures of piping only, and not to the vessel.

Boric acid is known to have a corrosive influence on metal. The history of operating experience has many examples of this effect. Regulatory authorities have in the past issued warnings on the interaction of concentrated boric acid with pressure vessel steel. Remedial actions include periodic inspections, and cleaning of any contaminants before a strong concentration can build up.

For a moderate range of failures the existing safety equipment that is, the Emergency Core Coolant System would probably provide sufficient protection, but this situation represented an unanalyzed condition at the time of the occurrence.

This photograph shows the effects of buildup and concentration of boric acid near the bolting area where the upper head attaches to the main portion of the reactor vessel (source: USNRC).

Lessons learned

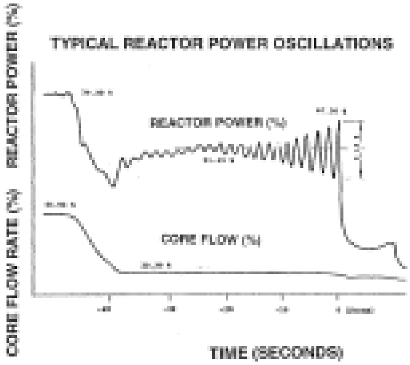
The direct cause of this event was boric acid corrosion, where the boric acid originated from leaks from the primary coolant system. Periodic inspection and cleaning of deposits is needed to detect and limit significant degradation of the vessel.

Contributory causes include a lack of consideration of operating experience, since several precursors in various countries have been reported over the past 16 years.

In general, the pressure boundary surveillance program should be broadened, as shortcomings in the management of safety were considered as part of the root causes.

2.2 Experience with reactor power stability

Power stability is one of the fundamental aspects in the design of Boiling Water Reactors (BWRs). Reactor core and associated coolant, control and protection systems are designed such that power oscillations affecting fuel design limits are not possible or can be reliably detected and suppressed.



An example of BWR power oscillations is shown here. In some cases oscillations may be started by flow decrease (as shown here) such the power to flow ratio is in or near a zone of instability. The instability zone is also defined by other factors, and is a complex phenomenon (source: USNRC).

Summary of reported events

In these events, highly divergent power oscillations developed in the core and were terminated by automatic shutdown (scram) of the reactor, or, in some cases, by a selected rod insertion or scram. No fuel damage resulted. One event was initiated by unfavourable power distribution in the core and another event by an electrical disturbance.

Safety significance

Instabilities increase the risk for fuel cladding failure due to temperature variations. Undetected instabilities can give rise to large global oscillations. Large oscillations are normally detected by the reactor protection system and effectively terminated by the scram before fuel limits are exceeded.

Lessons learned

In one event the main contributor to the instability was the core power distribution at the time of the incident, as well as an increase in the decay ratio (variation of peak amplitudes between successive oscillation cycles) over the years. Better monitoring instrumentation and trend evaluation were among a number of remedial actions for this type of event.

2.3 Experience with software problems

Advancing computer technology has allowed computer software to become an integral part of the many systems and processes that operate and support nuclear power plants. The role of these systems in maintaining safe operation of the plant depends on the reliability of the software as a component in the system. Software design, operation and maintenance are, therefore, subject to engineering standards and verification and validation methods appropriate to their criticality and safety impact.

Summary of reported events

International operating experience includes examples of events due to computer problems including, e.g. incorrect algorithms thus having a wide common cause failure potential. As another example of a worldwide effort during the reporting period, there was a concern before the year 2000 (Y2K) associated with digital systems involving potential date-related errors with embedded software devices and software applications. An application or a device would misinterpret the numbers "00" to represent the year 1900 rather than 2000. The resulting error could have caused the failure of the computer to operate. Software based systems perform functions such as post-accident sampling, fuel handling, core power distribution monitoring, and radiation monitoring and reactor vessel level measurement.

Safety significance

During the extensive projects all over the world, incorrect dates have been identified in safety-related printouts such as radiation monitoring. However, they have not affected the functions performed by the devices or systems. On the other hand, some non-safety related functions such as digital feed-water controls were affected by the Y2K problem and have required remediation. These balance-of-plant functions are critical for power generation but not for safety.

Lessons learned

Active management oversight is vital for the effective management of software based instrumentation, control and protection. Central control of Y2K activities, independent peer reviews, and thorough quality assurance involvement promoted consistency across program activities and products. In addition, it was recognized that sharing of information via owners group and utility alliance aided operators in the implementation of effective Y2K programs.

Operating organizations and regulatory authorities have recognized that the use of digital systems brings new and different types of concerns. The associated software has dependencies and failure modes that differ from analog systems and components of safety and control. This is an emerging area of reporting and analysis. The detection of and reaction, e.g. to the Y2K problem indicates that the nuclear community has an ability to detect and suppress safety concerns in a proactive manner.

2.4 Experience with system losses due to severe weather conditions

Nuclear power plant structures, systems, and components important to safety are designed to withstand the external effects of natural phenomena such as earthquakes, tornadoes, hurricanes, or floods without loss of capability to perform their safety functions. Components are also protected against internal flooding by applying environmental qualification measures and physical separation of redundant equipment.

Summary of reported events

Severe weather conditions resulted in the formation of waves moving up the river along which the plant is located, causing a partial flooding of two reactor units. External power supplies were lost momentarily due to the loss of the grid. Mechanical and electrical penetrations were damaged. Rooms housing safety related components were flooded causing their unavailability. This included portions or all of the Essential Service Water System, the Safety Injection System, and the Containment Spray System.

Moreover, due to the consequences of the storm, the site was momentarily isolated, impairing emergency help from outside. The plants were placed in a safe shutdown state.

Debris accumulation outside the chain-link fence indicates water level above the site platform (source: IRSN, France).

Safety significance

Bringing and maintaining the reactor in a safe shutdown state to cope with the consequences of the flood requires the availability of the corresponding equipment. Some of the equipment was made unavailable by flooding.A failure of a penetration protecting one train of the Essential Service Water System, similar to the one having affected the redundant train, would have led to a loss of the ultimate heat sink. This scenario is addressed by the safety related studies, but the flooding conditions of the rooms would have complicated the management of the situation.

Lessons learned

Although flooding is addressed in the plant design, this event revealed that conditions can be encountered where further improvements in design are desirable.

Assessment of the risks associated with internal and external flooding is essential in identifying defence in depth provisions to cope with these risks. Isolation of the site is a specific consequence of an external event which must be taken into account when defining the required emergency provisions.

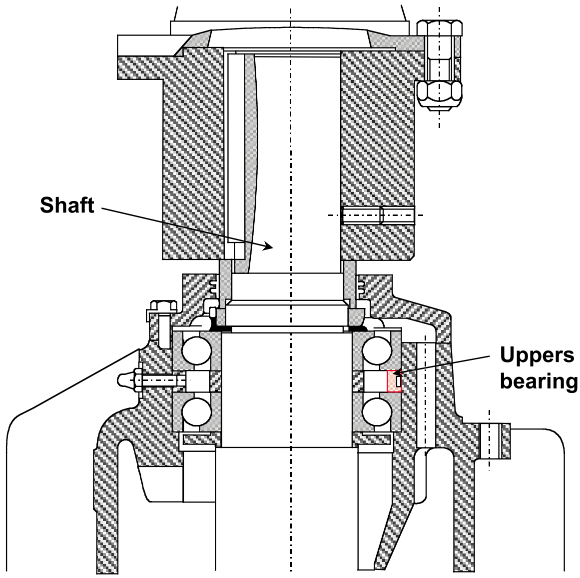
Nuclear Power Plants are designed to withstand the external effects of natural phenomena such as tornadoes for sites where their occurrence cannot be excluded (source: COG, Canada).

2.5 Experience with maintenance and modification control

Maintenance and modifications of nuclear power reactors are performed in accordance with standards and quality assurance programs to ensure the reliability of equipment throughout their mission and the availability of safety systems when they are called upon.

Summary of reported events

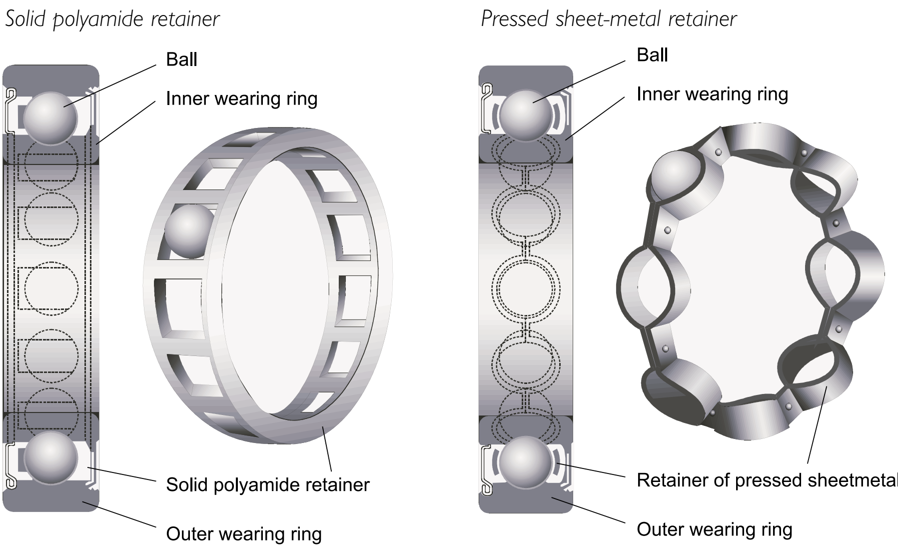
Retainers of pump bearings were discovered to be made of polyamide and not of the metal for which equipment qualifications were acquired. In other events, inadequate lubrication of equipment due to the use of insufficient amount of lubricant, ageing lubricants or mixing incompatible ones, were reported to represent potential risk of common cause failures of pumps, circuit breakers and valves. A modification of a cleaning technique of high-pressure jet spraying for boiler tube sheets caused material erosion of the boiler tube surface.



Upper part of a safety injection pump (source: IRSN, France).

Safety significance

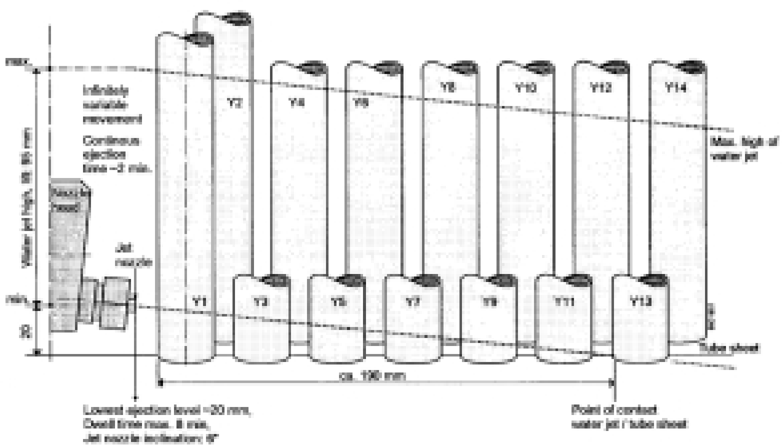
The use of incorrect material or part, in the case of the pump bearing for example, could destabilize the pump shaft leading to the loss of the pump and the safety function of the system. Because the same deficiency may be introduced in more than one pump, the deficiency could result in a common cause failure. In another example, material erosion (by high pressure jet spraying) of boiler tube surface could lead to degradation of the pressure boundary of the coolant system.



Source: IRSN, France

Lessons learned

Improved quality control, especially when engineered safety features are concerned, should minimize the introduction of latent common cause failures. The institution of preventative maintenance and condition monitoring programs represents additional barriers against surprise failures. Modifications to maintenance techniques should undergo qualification testing to ensure no adverse effect on components being maintained.



High pressure jet spraying for steam generator tube sheet cleaning (source: GRS, Germany)

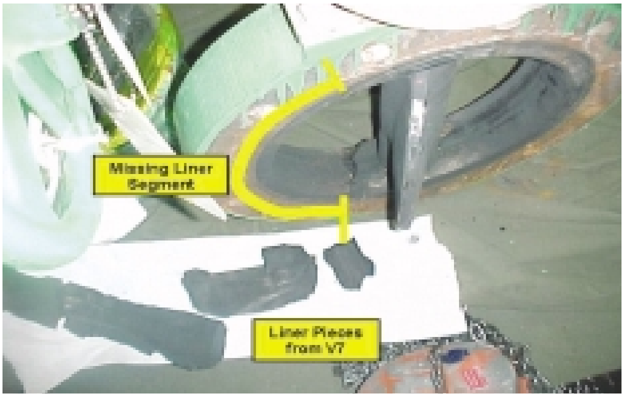
2.6 Experience with pump failures

Pumps in nuclear power plants are used to feed and circulate coolant throughout the cooling systems and to transport the heat removed from the nuclear fuel to the steam generators.

Summary of reported events

Fragments of the rotating wear ring from the heat transport feed pump were lodged in a valve. The ring had cracked due to stress corrosion cracking. In another case, foreign material entered into the cavity of the mechanical seal of a primary circulating pump causing the abrasion of the inner sliding surfaces and a high seal leakage flow.

Debris found in the valve
(A 1" diameter bolt is placed beside the debris for comparison.)



Valve showing liner segment.

Source: COG, Canada

Safety significance

Inadequate surveillance testing which does not monitor all relevant pump operating conditions, combined with inadequate assessment of oil analysis results, may allow severe pump degradation to go undetected. This degradation and the subsequent release of debris fragments could cause the impairment of the pump's performance of its safety-related function and the degradation of the fuel channel integrity.

Lessons learned

Component wear generates small size particles. Improved surveillance procedures and preventive maintenance techniques should control these small particles. By actively pursuing the root cause of high particle count in oil samples, damage to pump components can be discovered early. As well, improving the methods of flushing foreign material should minimize its impact on reactor systems.

2.7 Experience with fire protection

Fire protection systems protect areas housing both safety-related and non-safety related equipment used to safely shutdown the plant during fire. They are designed to provide primary fire protection and to meet certain regulatory requirements.

Summary of reported events

Failures of fire protection sprinkler heads and deluge valves were reported to be caused by poor design, deficient maintenance or inadequate testing. Other events pointed to potential safety hazards associated with the discharge of carbon dioxide (CO_2) from fire protection systems in the vicinity of the control room.

The habitability of control rooms in nuclear power plants is assured through the application of highest environmental standards (source: COG, Canada).

Safety significance

The automatic discharge of CO_2 in the vicinity of the control room may have adverse effect on the operator's ability to shut down the plant and could prevent access to stairwells and rooms containing equipment important to safety.

Lessons learned

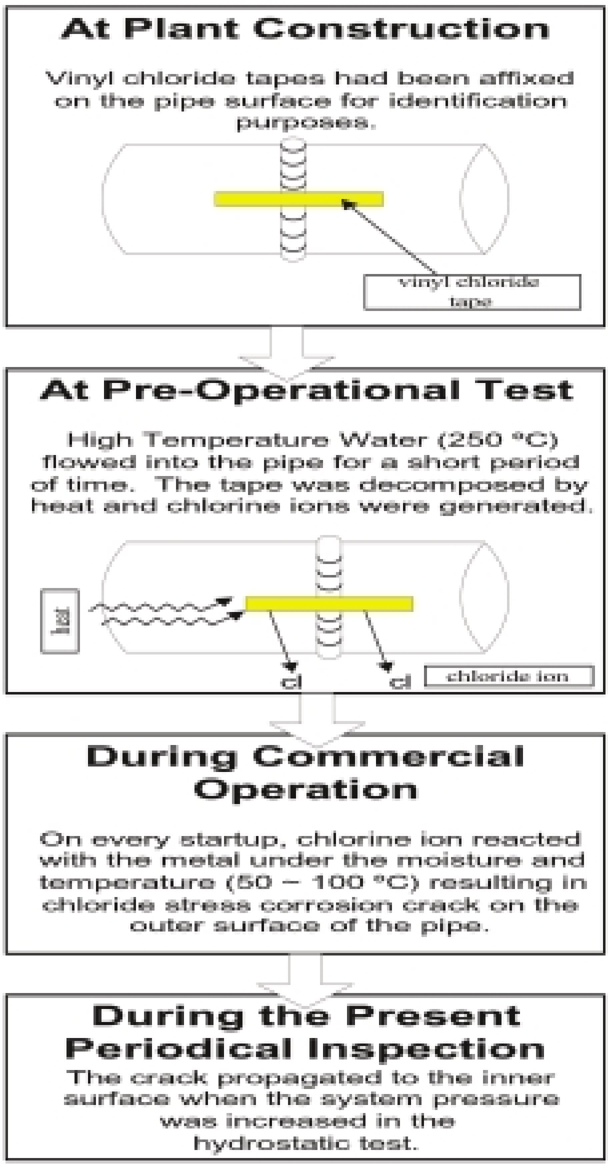
Measures to avoid or cope with inadvertent CO_2 discharges included modification of automatic CO_2 function so that it actuates manually, training on the use of breathing apparatus and review of procedures for isolation of areas potentially affected by CO_2.

2.8 Experience with cracks and vibration

Component and pressure boundary integrity in nuclear power plants is assured by making provisions in the design and manufacture for monitoring at intervals during the life of the plant. Besides weakening the integrity of the metal structure, cracks can be a source for coolant leakage or the release of radioactive fission products.

Summary of reported events

A crack discovered on a small pipe in the vicinity of a weld was attributed to stress corrosion due to chlorine tapes used to identify the piping during plant construction. In other events, cracks were attributed to unfavourable heat treatment or, in the case of feed lines, to a combination of cyclic stress (from vibration) and rigidly welding the lines to plate penetrations on a wall between a room and a vault.



Source: METI, Japan

Safety significance

Surface indications or small cracks have the potential to grow and propagate, depending on their locations. Small cracks may proceed to small leaks which, in turn, might result in release of radioactivity, corrosion of the pressure boundary or instrumentation and piping support damage.

Lessons learned

Greater attention paid to monitoring and early determination of the root cause of the cracks ands metal flaws, allow their potential impact to be assessed and addressed. Nuclear power plants operators place emphasis on the periodic visual inspections as part of the preventative maintenance.

2.9 Experience with management of safety

Safety management in a nuclear power plant is aimed at ensuring the plant is operated in a manner that adequately protects workers, the public, and the environment. Management involves the establishment of programs such as: quality assurance; maintenance of safety systems; emergency preparedness; or radiological protection of workers, the public and the environment.

Summary of reported events

Inappropriate human action during testing, poor work practices, or working on the wrong equipment were reported to cause failures in safety system trains, uncontrolled leaks or non-compliances with the radiation protection rules. In other events, similar consequences occurred due to a combination of inappropriate human action and equipment failure.

Safety significance

Management systems in nuclear power plants are fundamental barriers in addition to the existing physical safety barriers against equipment failures, personnel exposure to radiation or the release of radioactivity. Weaknesses in management systems, therefore, degrade the defence-in-depth and cause, directly or indirectly, events to occur.

Lessons learned

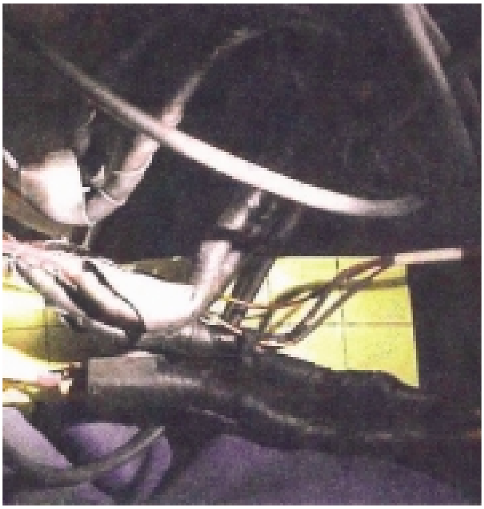
Proper management is vital in establishing authorized procedures, emphasizing strict adherence to procedures, proper application of the requirements and in correcting problems in a timely manner. More training, better pre-job briefings, self-checking, independent verification by others, closer supervision or improved procedures might have prevented these events. Promoting a questioning attitude and performing periodic safety reviews could reveal failures that may not have been discovered by routine surveillance. Thorough development of radiological work plans minimizes the radiological risks.

2.10 Experience with management of equipment ageing

As nuclear power plants continue to age, the management and mitigation of the effects of equipment degradation as a result of ageing become increasingly more important. Efforts to manage aging are aimed at ensuring that the effects of degradation do not compromise the safety function this equipment performs.

Summary of reported events

In one event, cables were found badly deteriorated due to a higher-than-normal temperature environment. In other events, components of the containment pre-stressing systems, which play an important role in ensuring containment integrity, were degraded. The containment structure serves as the final barrier against the release of fission products to the environment.



Environmental ageing of components such as electrical cables is of importance in maintaining safety of associated components and systems (source: USNRC).

Safety significance

Postulated accidents may result in a harsh environment which challenges the integrity of equipment needed to cope with the consequences, and may also result in challenging the integrity of the containment. Aged equipment may fail to perform their safety functions.

Lessons learned

Changes to the environment for which components are qualified to operate may occur due to weaknesses in the design or lack of monitoring and surveillance activities. Although equipment in power reactors is environmentally qualified to operate effectively during accident conditions, changes in the assumed normal environment over time could accelerate the ageing process. Inspections, condition monitoring, periodic evaluations and replacement of aged components are among the corrective actions taken to cope with aged equipment.

3. INSIGHTS FROM THE IRS STUDIES AND MEETINGS

3.1 In-depth discussions

The International Atomic Energy Agency (IAEA) and the Nuclear Energy Agency (NEA) sponsor annual meetings where delegates from participating countries gather to discuss recent events of special interest; to have in-depth discussions on selected topics; to review the operation of the IRS; and to discuss and evaluate generic studies. This section contains a summary of in-depth discussions on two topics that were found of special interest during the reporting period.

Topic No. 1: Outsourcing and its Impact on Nuclear Safety

Outsourcing is putting human resource professionals or skilled workers on contract to perform work for the organisation. It is a strategic tool used by management to optimize the use of resources to cope with competitive market forces. An increasing number of nuclear power plants now use contractors to perform design, maintenance or operation work under their supervision or management. In the course of performing contracted work at nuclear power plants, a number of incidents were encountered and were attributed to contractors' activities. Common agreement was reached among the specialists on the following points:

- Although contractors bring to the host organisation their advanced knowledge, resources and expertise, they must accept and perform their work under procedures and controls of the organisation. The fact that contractors are experienced should not mean that the operating organisation become complacent in ensuring adherence to plant procedures.
- The operating organisation should ensure contractors adhere to quality assurance and radiation protection programmes.
- Training of contractual personnel should focus on their understanding and acceptance of the safety standards and policies for work in nuclear power plants.
- The operating organisation should ensure that contractors follow installation criteria and should use a quality inspection programme to verify the quality of the installation.

Topic No. 2: Electrical Systems Events

Nuclear power plants generate electric power and supply it to the offsite grid. The plants themselves require electric power to operate plant systems for cooling the nuc-lear fuel and maintaining other vital equipment and services. To assure reliable electric power for all circumstances, on-site standby electric power supplies, such as diesel generators, are provided as a backup to the offsite grid supply. Both off-site and on-site power supplies are important for maintaining nuclear safety.

The specialists who participated in this discussion focussed on the reliability of the off-site power supplies. They noted that the degraded voltage can impair the operation of equipment and sometimes does not produce the transfer of plant loads to the on-site emergency power supplies. The specialists also discussed failures of power plant electrical relays that could impact electrical system performance. Manufacturing problems as well as deficiencies in quality checks were the causes for the defective nuclear grade relays. The remedial measures were to initiate additional surveillance and relay testing before installation.

The specialists recommended the initiation of an IRS study of electric issues, including the reliability of electric supplies and ageing of relays.

A 230 kV conductor on the jaw side of a disconnect switch was found broken and hanging freely (source: COG, Canada)

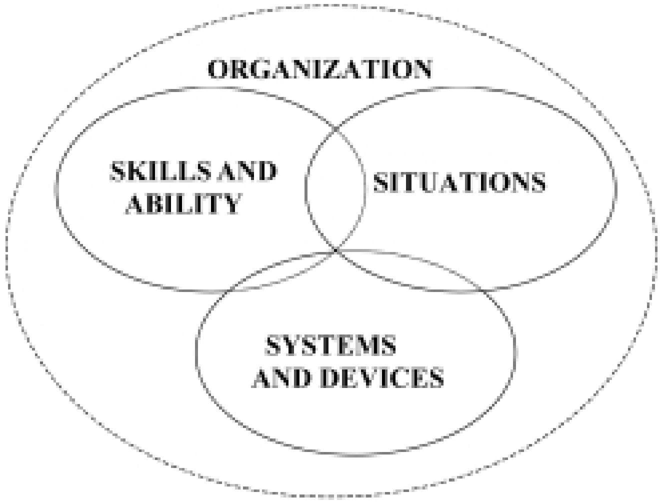
3.2 Generic or topical studies

Study No. 1: Interaction between Procedures and Human Activity

Procedures used in nuclear power plants may be viewed as tools to direct, guide, and inform operating and maintenance personnel in nuclear power plants. They include operating, maintenance and test procedures; operating guidelines; and technical notices. Procedures are applied in a context which can be defined by:

- the skill and ability level of the users responsible for applying them;
- the situations in which they are applied; and
- the technical or material systems and devices on which they are applied.

These three areas interact with each other in a manner that is unique to each plant or organization. Consequently, each plant or organization will enact its own policy or strategy to produce, edit, validate, and update its procedures.



The study team analyzed a number of nuclear power plant events to explore the types of procedural deficiencies and their impact on the user performance. The team observed some recurrent problems and made recommendations to address these problems:

- In several events, the procedure user did not understand the information presented in the procedure because it was unclear or confusing. This concern is especially important in abnormal or emergency situations where the procedure user does not have time to obtain clarification from the procedure writing authority. An effective way is to have typical users review the procedure, and encourage them to comment on information they think others may not understand.
- Procedures generally impose a rigid sequence on actions that may not be appropriate in an evolving scenario. Procedures, therefore, should take into account the dynamic conditions in the plant.
- Last minute changes are frequently made to a procedure using hand-written annotations before the procedure is performed. These changes can often lead to problems. The need for last-minute changes should be minimized by reviewing procedures on a regular basis.
- A problem most commonly reported was that the procedures provide very brief information. Special attention should be paid to the level of detail during validation and verification of the procedures.
- When users were faced with a procedure which they believed to be incorrect or otherwise deficient, users deviated from the procedure. Policies on procedure compliance should be clearly stated, and plants that institute a verbatim compliance policy need to consider producing procedures of exceptionally high quality, because users will be forced to follow them.

Study No. 2: Staying Safe is to Stay Within Limits

Nuclear reactors operations involve systems, equipment and a number of measured parameters such as power, coolant flow, coolant temperature, etc. The availability of each piece of equipment and the magnitude of each parameter are monitored and controlled to ensure that they stay within pre-defined safe limits. The reactor operator is responsible for maintaining the operation within these limits in accordance with a set of rules known as "Operational Limits and Conditions" (OL&C). Operation within these limits ensures adequate safety margin and minimizes the risk of encountering incidents or accidents.

A group of experts at the IAEA examined events reported by several countries to determine why and how the OL&C were unintentionally exceeded with the objective of transferring lessons learned to member countries. Their findings were issued in a report entitled *"NPP events which indicate non-compliance with operational limits and conditions".*

The group found that in some cases the procedures for operating or maintaining equipment were not adequate. In other cases, the instrumentation or the alarms associated with the monitored or controlled parameters were also not adequate. Efficient testing and re-qualification of equipment after performing maintenance work on them were found to be important in ensuring that equipment are restored to their operable status and are available when called upon to operate.

The most contributing factor to the deviations from the OL&C appeared to be in the area of human performance. For example, while the OL&C themselves were generally well maintained, the manner in which their requirements were transferred to other operating documents was reported to be deficient. Other deviations from limits were attributed to lack of visual indications of OL&C on monitoring instrumentation.

The group emphasized the need to expand the concept of "surveillance" to include not only surveillance tests, but also other means such as plant walkthroughs so that inoperable equipment can be detected promptly.

Although operators take adherence to OL&C seriously, the group cautioned that competitive market pressure may tempt operators to operate closer to limits and could result in increased deviations from the limits. Nuclear operators were also encouraged to identify and trend specific deviations in their plant.

Study No. 3: Corporate Knowledge: How it can be lost and how to maintain it?

The term "Corporate knowledge" refers to the combination of information, skills and experience related to the purpose or activities of an organisation that is stored or held within that organisation. Corporate knowledge can be generated within the organisation or collected from outside sources.

Recognizing that loss of corporate knowledge could contribute to the occurrence of incidents, the IAEA initiated a study and issued a report entitled *"NPP events caused by loss of corporate knowledge and memory".* The study surveyed reported incidents and identified the most common circumstances under which the loss of corporate knowledge could occur. These are:

- *Staff turnover:* This occurs through retirement, resignations, terminations, transfers and layoffs. The accumulated knowledge of the experienced staff, which is often extensive, can be lost when knowledge is not transferred from the outgoing to the incoming staff.
- *Unavailability of information:* This occurs when information is not recorded or not archived appropriately or when information is not provided through pre-job briefing. Of particular importance is the availability of the as-built design knowledge that changes over the life of the facility and which should be passed on during the transition from commissioning to operation and through to the decommissioning phase.
- *Ineffective use or application of knowledge:* Despite the existence of information within the organisation, individuals may not be aware or may not understand they had access to information. Others thought information may not be applicable, or were not given sufficient time or an appropriate work environment to apply the knowledge. Inadequate extraction of "Lessons learned" through the review of the existing sources for operating experience, such as the reported incidents, constitutes ineffective use or application of existing knowledge.

The study made a number of recommendations calling for strengthening the operating experience programs to ensure effective capturing of the lessons learned and making them available to all users. Programs for pre-job briefing could also be improved to clarify the situations under which the briefing should be conducted. Organisations should develop succession plans to respond to all situations involving staff movements. Efforts to preserve knowledge within the organisation should be extended to retain and attract experienced and specialised staff through, for example, incentive programmes.

Study No. 4: Requalification of Safety Related Equipment Following Outages

Maintenance of safety related equipment during plant outages is aimed at ensuring their operability within the conditions stipulated in the technical specifications of the plant, before returning them to service. Such operability can be further assured by conducting "Requalification" testing following maintenance. Requalification, when performed successfully, should therefore resemble an additional barrier within the principle of defence-in-depth, and allow a safe plant start-up.

This generic study was prompted by a number of events where safety significant equipment was found inoperable after maintenance outages. Analyses of these events traced the causes to problems with requalification testing, which involved inappropriate human actions, organisational deficiencies and technical problems.

The inappropriate human actions included failures to carry out the tests correctly. The organisational deficiencies were due to problems in the scheduling of requalification tests and deficiencies in the documentation and communication. The technical problems generally involved inadequacies of the specifications for the test conditions, test procedures or the tools used.

While the remedial actions taken in response to the requalification problems were found to be event specific, personnel training and procedure changes were reported in several events. Some countries reported on a systematic requalification programme for equipment including several good practices.

The following recommendations were made in the study:

- Requalification should be treated as an integral part of the maintenance activities and should be prepared before starting these activities, regardless of their scheduling.
- Maintenance documents should make it possible to trace the planning and execution of the maintenance activities and the results of tests.
- Since requalification tests require staff of a wide range of skills involving maintenance, operations and other activities, responsibilities must be clearly assigned during the planning phase and tasks should be subject to overall coordination.
- Equipment should not be declared operable before the results of requalification and the resolution of any deviations become available.
- Plant Management should ensure that plant operators learn from the experience gained during the requalification.

3.3 Specialists meetings and workshops

Specialists Meeting No. 1: Preventing Incidents Requires Tools and Methodologies

Nuclear facilities, like any other industrial facility, may encounter incidents or accidents in the course of operation. While many of these incidents have no actual safety consequences, yet they represent potential for more serious occurrences if left unanalysed. To prevent the occurrence or recurrence of these incidents, the nuclear industry and regulators have developed over the years methods and approaches aimed at investigating single or groups of incidents and formulating the appropriate remedial actions. Lessons learned from investigating an incident in one facility would then be fed back to other nuclear facilities, thus achieving maximum safety benefit and preventing recurrence.

In 1997, the IAEA launched a Coordinated Research Project (CRP) to examine incident investigation methodologies utilized by different organisations around the world. Fourteen research organisations participated in this program and issued its findings in a report entitled *"Investigation of Methodologies for Incident Analysis"*. They explored the strengths and weaknesses of each method and made recommendations for the applicability of different methods to different incidents and situations.

The effectiveness of corrective and remedial actions that result from the use of these investigation methods was also studied in depth. The CRP report provided guidance on how to make the remedial actions more effective. Economic or work environment may not allow the implementation of all remedial actions immediately. The CRP report, therefore, reviewed the factors that should be considered when prioritizing their implementation.

The CRP report emphasized the important role that top management plays in supporting the process of feedback of lessons learned from these incidents and the commitment they make to oversee the implementation of the remedial actions.

Specialist Meeting No. 2: Recurring Events

The NEA in co-operation with WANO and the IAEA held a workshop to provide a forum for presentations and open discussion on the subject of recurring events at nuclear power plants. Staff members of nuclear power plants, regulatory bodies and technical support organisations participated in this workshop. A definition of a recurring event was adopted by the workshop as:

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 organization.*

Participants discussed insights into the aspects of recurring events using the operating experience data, event analyses. They also explored means of identifying and investigating the recurring events with a view to recommend remedial actions to reduce the likelihood of their recurrence, both on national and international levels.

The workshop arrived at the following conclusions:

- Nuclear Power Plants (NPPs) should review events reported by other plants, both domestically and internationally, to identify and implement lessons learned with the objective of preventing recurrence.

- Event investigation processes, currently used by some NPPs and regulatory bodies, may not be sufficiently focused on the recurring aspects of events.

- Event investigation processes should place more emphasis on why the actions taken after the first event have failed to prevent the recurrence of the latter event(s).

- Events that are identified as recurring should be brought to the attention of the plant and regulatory body management, since their investigations often identify possible weaknesses in organisational processes, such as corrective action programmes, change control processes, and training.

- The IAEA/NEA IRS system and its associated studies may be missing a number of recurring events. This is due to the current rule that states that, for a recurring event, it only needs to be reported if there is a "new important lesson learned".

- A widely accepted definition of recurring events by all NPPs and regulatory bodies is desirable so that consistent identification of recurring events is made in all member countries.

4. CLOSING REMARKS

The operation of a nuclear power plant involves a large number of systems with thousands of mechanical and electrical components. The application of the concept of defence in depth throughout design and operation provides a graded protection against a wide variety of transients, anticipated operational occurrences, incidents and accidents, including those resulting from equipment failure or human action within the plant, and events that originate outside the plant. This concept involves a series of levels of defence (inherent features, equipment and procedures) aimed at preventing accidents and ensuring appropriate protection in the event that prevention fails.

For events involving failures in operating devices or in human and organizational performance, it is important to analyze the event, to identify its causes and draw lessons, in order to avoid the recurrence of similar events or to ensure with additional defences that their consequences remain small.

This important process is known as operating experience (OE) feedback. Operating experience feedback programs are intended to facilitate the development of proposals for remedial actions such as changes in plant and system designs, operating procedures and maintenance programs. This experience is important not only for the individual plant where the event occurred, but also for other plants, including those in other countries. It is therefore particularly useful to share experience among Member States contributing to the Incident Reporting System, so that all countries with nuclear power plants can draw from a richer dataset. The analysis may be completed by a prospective review of operating experience, so that hazards and precursors of significant events are detected and corrective measures are adopted proactively.

As with any human endeavour, there is always room for improvement. Over the past years there has been a gradual reduction in the reporting rate of events to IRS system. As observed in Section 1, this reduction may be partly attributed to the rigorous application of operating experience feedback programs and the adoption of the lessons learned throughout the world. However, there is a concern that diminished reporting might also in part be due to a shortage of resources in the operating experience feedback loop. Furthermore, recurrence of events indicates that vigilance is required to ensure that lessons learnt in the past are retained in the knowledge of nuclear organizations and continue to be applied.

Overall, the operating experience feedback systems are providing invaluable services to the operational safety characteristic of nuclear power plants. From event detection, to reporting, to dissemination among Member States and finally, to specification and installation of corrective actions, there is evidence that experience feedback is operating correctly in the closed loop mode and thereby leading to improvements. More than 250 events have been reviewed by national IRS coordinators and by international meetings for this periodic report, which has enabled experts to highlight emerging areas for improvement in nuclear safety.

It is a wish of the IRS community that this periodic report will be helpful in showing important causal mechanisms and suggesting lessons to be learned for the various areas of nuclear safety.