# Nuclear Power Plant Operating Experience

## from the IAEA/NEA International Reporting System for Operating Experience

## 2005–2008

IAEA
International Atomic Energy Agency

AEN
NEA

# NUCLEAR POWER PLANT
# OPERATING EXPERIENCE
# FROM THE IAEA/NEA
# INTERNATIONAL REPORTING SYSTEM
# FOR OPERATING EXPERIENCE
# 2005–2008

The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

# NUCLEAR POWER PLANT OPERATING EXPERIENCE FROM THE IAEA/NEA INTERNATIONAL REPORTING SYSTEM FOR OPERATING EXPERIENCE 2005–2008

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

Three editions of this report have been published, in 2000, 2003 and 2006, covering experience during 1996–1999, 1999–2002 and 2002–2005, respectively.

This fourth report, on nuclear power plant operating experience from the IAEA/NEA International Reporting System for Operating Experience, covering the 2005–2008 period, follows on the success of the previous three. This edition highlights important lessons learned, 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.

The IAEA officer responsible for this publication was X. Bernard-Bruls of the Division of Nuclear Installation Safety.

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# SUMMARY

During the reporting period of this publication, no nuclear reactor accidents occurred worldwide. This may be attributed in part to the success of operating experience feedback, including the International Reporting System for Operating Experience (IRS). The majority of the events reported to the IRS during this period had previously known causes. Yet some events that took place revealed new phenomena or unexpected aggravating conditions. There is an ongoing challenge in closing the feedback loop and sharing lessons learned to prevent recurring events. The key issues identified during the reporting period of 2005 to 2008 are highlighted below.

(a) Communication

Current events continue to highlight both the successes and failures of communication. The events reviewed point out the need for effective communication within an organization, through all levels and across organizational boundaries. All involved parties must be aware of and recognize the potential impact of their activities on others. Organizations must stop and look outside their own boundaries to see who else may be impacted, or who may be impacting them. The continuously changing environment in today's nuclear industry requires added diligence to ensure that communication is clear, concise and complete.

(b) Operating experience and event information sharing

A lack of sharing of information on operating experience is one of the major contributors to some events. If previous similar events had been recognized throughout the industry, their recurrence might have been avoided. These events imply that it is important to disseminate information on operating experience, incorporate the appropriate corrective actions based on the lessons learned from previous events, and prepare and execute training programmes for plant personnel and contractor staff.

(c) New equipment

The need for replacement of instrumentation and control equipment is a common challenge in nuclear reactors with long operating periods. In many instances this entails changing from hard wired technology to software based equipment. This will lead to the simultaneous use of old and new technology. Some safety significant events show that thorough understanding of new technology and its performance, together with old technology under normal and transient situations has to be ensured. Proper testing and surveillance are proven methods of confirming the specified operability of such systems after initial installation. In addition, the proper planning of testing and surveillance can significantly reduce latent failures.

(d) Recurring common cause failures

Common cause vulnerabilities continue to be reported. In this report, vulnerabilities regarding common cause failures in emergency diesel generators and essential cooling systems are highlighted. Improving surveillance programmes and performing root cause analysis extended to redundant systems and implementing effective corrective actions are significant steps towards enhancing the safety of nuclear installations.

(e) Recurring foreign material intrusion

Intrusion of foreign material continues to occur, confirming that this issue is a recurring concern deserving more attention from both management and regulatory bodies. Foreign material can move to other parts of the system, damaging internals of important equipment, affecting the satisfactory performance of critical functions or leading to their partial or total unavailability in an accident condition. The events reviewed emphasized the importance of foreign material exclusion programmes.

(f) Radiological controls

Personnel safety is a common goal of the entire nuclear industry. Protection of workers, the general public and the environment is a universal value that everyone shares. The lessons learned from the events reviewed show the need to continuously focus on this issue. Releases to the environment and exposure to personnel continue to happen. Changes in technologies and risk management may require a new review of safety practices. Careful preparation of critical operations is paramount.

(g) Safety margin

Many events have neither real safety consequences, nor do they cause a loss or degradation of safety function. However, these situations may result in a decrease of conservatism built into the design of the plant, and thus cause a reduction in the safety margin. This may lead to ageing of the equipment or an increase of the probability of accident situations if one minor deviation coincides with another failure or an unfavourable plant condition. Therefore, such events should be thoroughly analysed and conservative actions taken.

# 1. THE INTERNATIONAL REPORTING SYSTEM FOR OPERATING EXPERIENCE (IRS)

## 1.1. WHAT IS THE IRS?

At the end of 1978, the OECD/NEA took the initiative to establish an international system for exchanging information on safety related events in nuclear power plants. In 1981, OECD countries formally approved the operation of the IRS and in 1983 the IAEA extended the system to all Member States with nuclear power programmes. Since then the IRS has been jointly operated by the IAEA and the NEA. However, with the creation of the first comprehensive database on the IRS, the advanced incident reporting system (AIRS), in 1995, the responsibility for handling information on events (including quality checking) was transferred to the IAEA.

**Participating countries**

| | |
|---|---|
| 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 |
| Republic of Korea | |

The IRS, as a worldwide system, is designed to complement national schemes. Information reported is assessed, analysed and fed back to operating organizations to prevent similar occurrences. The ultimate objective is to enhance the safety of nuclear power plants by reducing the frequency and severity of safety significant unusual events worldwide.

The IRS is also interested in identifying ‘precursors’. These are events of apparent low safety significance which, if not properly monitored, have the potential to escalate into more serious incidents. Through the analysis of data reported to the IRS, the identification of these precursors can be facilitated and appropriate actions taken to mitigate their consequences. It is also important to detect and report on low level events and near misses, as well as recurrent events.

The IRS represents a systematic approach to provide feedback on lessons learned from operating experience, which is a key element of the ‘defence in depth’ philosophy used as a fundamental building block throughout the nuclear power industry.

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 organizations and regulatory bodies”.

## 1.2. WHAT ARE THE BENEFITS?

The IRS increases worldwide awareness of potential and actual problems in nuclear power plant operations. The heightened awareness generated by feedback from operating experience has resulted in numerous improvements to equipment, procedures and training in many nuclear power plants, thereby reducing the potential for subsequent failures that could result from unusual events.

The analysis of IRS reports can also assist in determining whether a particular event is generic or recurring in nature. Recurring events may reveal several types of problems related to the safety of nuclear power plants. A recurring event is defined as one with actual or potential safety significance that is the same as or similar to previous nuclear industry events, and has the same or similar causes as the previous events.

Examples could include loss of residual heat removal while at mid-loop (PWR), service water degradations due to bio-fouling, BWR power oscillations/instability, PWR vessel head corrosion, and/or steam generator tube rupture.

The IRS database contains event reports that provide detailed descriptions and preliminary analyses of the event's causes that may be relevant to other plants. The analysis may lead to corrective action by plant management or regulatory authorities. IRS resources include topical studies of events of particular interest. These studies have focused on the importance of human actions, common mode failures or fires, plant shutdown procedures and low power operation modes, and the need for constant vigilance during plant operations, improvements and modifications.

Countries that participate in the IRS benefit from exchanging information related to the root cause analysis and lessons learned from incidents at nuclear power plants. Feedback on how to adequately remedy or avoid possible precursors is of paramount importance to operational safety. For example, abnormal pipe thinning in short piping bends that is not identified in time could eventually lead to a pipe break, which in turn could result in an accident.

Another potential use of IRS data is the application of operational feedback in the design of the next generation of nuclear power plants. Nuclear power plant operating experience has demonstrated that design modifications documented in IRS reports can have a significant impact on safety.

## 1.3. HOW CAN THE IRS BENEFIT DECISION MAKERS?

Decision makers in the industry, regulatory bodies and nuclear organizations around the world face a challenging environment that includes deregulation, privatization, 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, a common safety goal. The IRS can play 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 systems information, in particular on high risk areas, in order to prioritize their programmes. They need to receive early warning of deteriorating safety performance in the field in order to maintain an acceptable level of safety. They also need to share experience and lessons learned with others, thus making efficient use of their resources.

Regulatory bodies require the industry to report on hazards or the potential for hazards so that they can tailor effective requirements, guides or standards that address actual or potential hazards in a manner that limits risk to the public.

The IRS is a global contact network and forum that enables safety experts around the world to share and review information on lessons learned from reported events. It can provide 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 prioritize those issues of safety significance that have been reported, and to assist in the identification of areas in which further resources or research is appropriate.

## 1.4. HOW DOES THE IRS WORK?

### Event reports

Each of the 31 member countries with an operating nuclear power plant designates a national IRS coordinator. Reporting to the IRS is based on the voluntary commitment of the participating countries. An event report is submitted to the IRS when the event is considered by the national coordinator to be of international interest. Events of safety significance and events from which lessons can be learned are reported according to guidelines. Safety significance is defined as follows:

(a) The event itself is serious or important in terms of safety due to an actual or potential significant reduction in the plant's defence in depth;
(b) The event reveals important lessons learned that would help the international nuclear community to prevent its recurrence as a safety significant event under aggravated conditions or to avoid the occurrence of a serious or important event;
(c) The event is similar to an event previously reported to the IRS, but highlights new important lessons learned.

When information is considered to be time sensitive, a short preliminary report can be distributed within one month of the event. Subsequently, a main report is produced and in some cases a follow-up report is generated and distributed when additional relevant information becomes available.

The main event report contains basic information, including the title and date of the event, characteristics of the plant and an abstract. It also includes a narrative description of the event, a preliminary safety assessment (what were the direct causes, consequences and implications), root cause analysis and potential corrective actions, lessons learned and guidewords containing the essential information that can be easily searched and retrieved. Often, a written description of the event is supported by graphics (diagrams of affected parts of the plant, etc.).

When an event or series of events indicates a generic problem (e.g. pilot operated valves), the national coordinator may produce what is known as a 'generic report'.

**Sharing information**

Each IRS report becomes part of the web based IRS, which was created to facilitate data input and report availability, and speeds up access to information. Passwords are provided to users depending upon access level, thus ensuring a high level of security. Once a new report is posted on the web based system the users will be informed by email. The routine receipt and distribution of reports on incidents form the basis for in-depth studies on implications and remedies, and assist in identifying safety issues common to nuclear power plants.

The incident reports included in the IRS are selected because they are of particular interest for the international nuclear community — whether due to important lessons that can be learned from them, the identification of new safety concerns or the interrelationship of events.

## 1.5. HOW IS THE IRS USED?

**Topical studies**

Topical studies constitute a major component of IRS related activities. Such studies are intended to provide the basis for generating in-depth evaluations and to identify topical or generic issues by a team of nuclear experts. These issues begin with a national assessment by the reporting country that is then studied in depth by experts at the international level, when warranted.

**Annual meetings**

National coordinators meet each year to review the information received and the operation of the system in general. The committee of national coordinators selects topics and reports of those events that it considers to be of particular safety interest to the international community for further analysis. Conclusions of the committee are distributed to participating countries. Moreover, a joint IAEA/NEA meeting to exchange information on unusual events is also held annually. These meetings serve to strengthen the mechanisms for the exchange of experience in the assessment of incidents and in improvements made to reduce the frequency of similar events.

**Restricted access**

Access to IRS reports is restricted. Because the system is designed to be of value mainly to technical experts working in the nuclear power field, the information reported is not intended for distribution to the general public. This restriction encourages openness within the nuclear community, including the disclosure of incident details and related plant actions.

**Other systems**

The IAEA and NEA also maintain the International Nuclear and Radiological Event Scale (INES). INES was introduced in 1990. Its primary purpose is to facilitate communications and understanding among the nuclear community, the media and the public on the safety significance of events occurring at nuclear installations. The scale was modified in 1992 to include any event associated with radioactive materials and/or radiation, including the transport of those materials. It is anticipated that events of safety significance reported to INES at level 2 and above will be included in the IRS.

**Other activities**

Activities within the IRS extend beyond the exchange and feedback of event information. Both the NEA and the IAEA have assigned expert working groups who meet annually and discuss the safety relevance of such events, the regulatory perspective, and the application of lessons learned.

## 1.6. WHAT HAS BEEN ACHIEVED?

Currently, 31 countries with nuclear power programmes participate in the IRS. There are now over 3500 event reports in the system. Additional events are added at the rate of about 80 per year. The annual reporting rate since 1980 is shown in Fig. 1. The reports are now being made available in a user-friendly web based system, with a full text database and a powerful search engine allowing full text searching. The capacity for data input, storage and access to written, numerical and graphic information is increasing the reporting and subsequent analytical capabilities and is making the IRS more effective in the enhancement of nuclear safety.

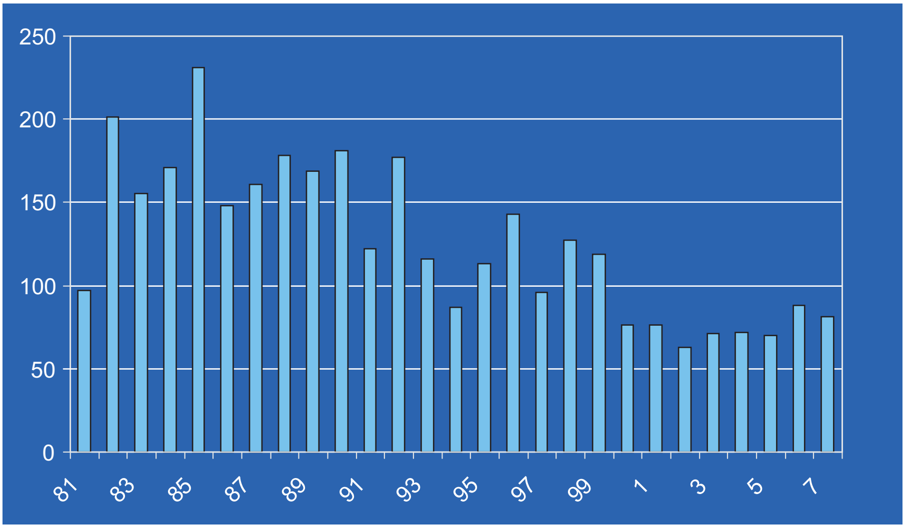


*FIG. 1. Annual reporting rate since 1980.*

Over the years, the IRS has expanded from being primarily a vehicle for information exchange to becoming a source for analysis, in-depth discussions, generic studies and meetings for the exchange of information related to operating experience.

Recently, an Event Review Group (ERG) was established within the IAEA's Division of Nuclear Installation Safety to review event reports for completeness, accuracy and consistency. The ERG meets regularly and works towards ensuring the quality of the reports posted on the web based IRS.

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

### 2.1. EXPERIENCE WITH EVENTS, INCLUDING THE LOSS OF OFF-SITE POWER

In the Blue Book 2002–2005, the discussion highlighted the safety significance of grid disturbances, even though no particular important event had occurred. Shortly after the publication of the Blue Book an event occurred, revealing more difficulties than predicted.

Maintenance work was being carried out at a switchyard, which is the connection of the nuclear power plant and the grid. In most cases the switchyard belongs to the grid operating organization. In the specific event, these maintenance activities were not performed according to the applicable procedures. The plant operating personnel were not informed of the ongoing work in the switchyard. The inadequate maintenance work resulted in a high voltage short circuit, which could not be isolated as foreseen in the design because of the configuration of the electrical bus bars at the switchyard.

A further independent maintenance error at the plant led to a high voltage spark propagating to the uninterruptable power supply system. In the end of the transient two out of four redundancies of the uninterruptable power supply, including the attached emergency diesel generators, were unavailable for about twenty minutes. A part of the control room annunciation was lost, making control of the event difficult for the personnel. But the reactor was automatically shut down and the residual heat was removed at all times.

In another event a similar high voltage peak was initiated by a newly installed electrical component of a low safety class in the main generator excitation system after a reactor trip. Even though this component has low safety significance, the voltage peak led to the loss of all redundancies of a safety system.

Several more recent events highlight the safety significance of the loss of off-site power and the potential on-site consequences. The causes include bad communication between the plant operating organization and the grid operating organization, deficiencies in the protection of low voltage electrical systems against high voltage sparks, as well as the replacement of hard wired electrical equipment by software based components.

**Safety significance**

The propagation of electrical disturbances from the grid into the power plant's low voltage electrical systems — especially the vital instrumentation and control system — is considered to be risk significant. As illustrated in the event the loss of off-site power can also result in the loss of on-site power. In this case the possibility of controlling the plant is significantly degraded if vital instrumentation and control is lost. The effects of manual operator measures might not be verified in the case of loss of control room annunciations.

From the beginning of nuclear power plant operation some vital plant controls have been designed to be 'fail safe', e.g. the insertion of the control rods to shut down the reactor. For physical reasons, others allow sufficient time for manual operator actions to control the vital safety functions in case of simultaneous loss of off-site and on-site power.

**Lessons learned**

The event resulted in important international activities to understand the technical reasons for the transient and to prevent recurrence. The main lessons comprised the models and calculations developed to simulate the dynamic behaviour of electrical systems. The interaction between the plant and the grid in case of severe grid disturbances has to be considered after replacement work in electrical systems. Replaced electrical components are today based on chip technology with hidden embedded functionalities. Many plants went into operation using classical equipment containing hard wired circuits, including transistors, resistors, capacitors and diodes. Even if designed for replacement, the specific behaviour of the new equipment may differ from the old equipment. Therefore, it is important to keep an updated agreement on operational and technical specifications and a comprehensive test programme after the installation of new electrical equipment.

As a generic lesson learned for regulatory bodies the event described and several further events reported to the IRS show that there is a need to develop guidelines on new safety related electrical equipment. This covers equipment with embedded functions, as well as fully computerized safety systems.

> Events initiated by the loss of off-site power cannot be fully avoided by the power plant operating organization. Grid operating organizations and plant operating organizations should communicate on planned and ongoing maintenance work at the grid and at the switchyards to minimize the potential impact of disturbances. Plant operating organizations should prepare for the occurrence of high voltage sparks to avoid degradation of safety related electrical equipment. The replacement of hard wired protective equipment by software based components has to be carefully planned and tested to prevent situations such as the propagation of high voltage disturbances into low voltage vital systems.

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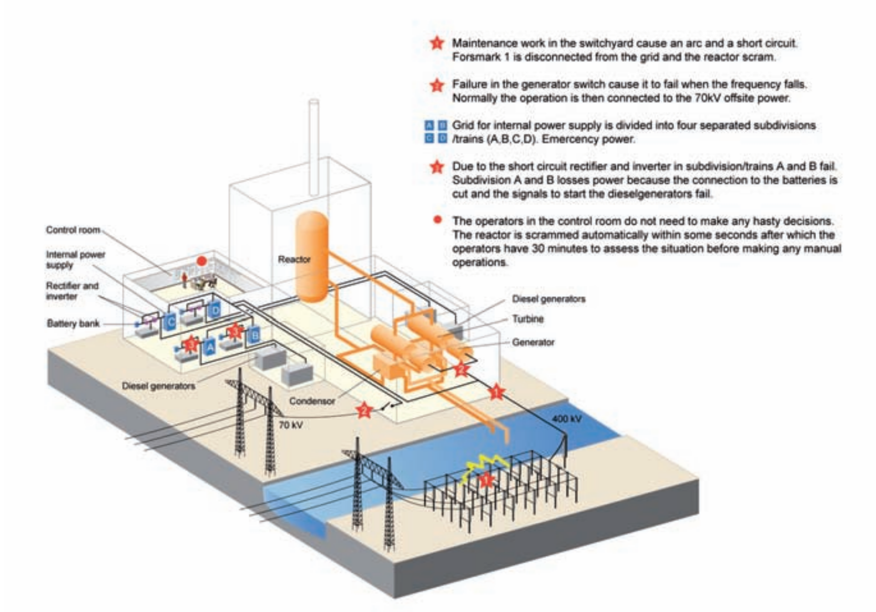


*FIG. 2. Due to a short circuit in a 400 kV switchyard, many plants worldwide analysed the behaviour of the uninterrupted power supply (UPS) systems and the independence between the different power supply systems (source: Swedish Radiation Safety Authority, IRS meeting 2006).*

## 2.2. EXPERIENCE WITH UNINTENTIONAL OR UNEXPECTED REACTIVITY INSERTION

During the period 2005–2008, three events involving unintentional or unexpected reactivity insertion were reported to the IRS.

An unintentional criticality event had occurred during the periodic inspection outage at a BWR plant. While doing work to enhance the capability of the reactor shutdown function, three control rods were partially withdrawn and the reactor became critical when the valves related to operation of the control rods were operated as a part of preparation for testing. As a result, an automatic reactor scram signal was generated and the withdrawal of the control rods was stopped. However, the control rods were not re-inserted automatically. Since the workers involved did not follow the procedures, the hydraulic pressure acted on the withdrawal side of the control rod, resulting in unintentional withdrawal. In addition, the test procedures were poorly prepared without any authorization. Furthermore, this event was not reported to the competent authority for several years. The data were falsified, and the event investigation was not conducted at that time.

The second incident is an unexpected reactivity excursion at a PWR plant after the cation bed demineralizer/ion exchanger was placed in service on the letdown line, caused by inadequate shutdown and startup procedures as well as poor communication among plant staff members.

In the third event, a wrong boron pump was selected during power operation, resulting in boron dilution. The major causes were insufficient check of procedures and poor communication among the shift crew.

**Safety significance**

Reactivity control is one of the most important features of reactor safety. These events were not severe because the abnormal situations were recovered in a short time. Although these events had no actual consequences on safety, they could have affected the fuel integrity if larger reactivity had been inserted. Also, the first event would have had a potential of exposure to workers involved if prolonged since it took place during the outage.

**Lessons learned**

For the first event, similar situations had been observed at other plants but the information was not shared among the relevant utilities and manufacturers. If the previous events had been recognized throughout the industry, this event might have been avoided. This event underlines the importance of information sharing in preventing such events from recurring.

In the second event, shutdown and startup procedures did not include precautions with respect to isolating/conditioning the demineralizer when going into an outage or during startup. The lesson learned from this event is the importance of following the precautions for use of such specific devices.

In the third event, no one checked the procedure and there was no peer checking to confirm that the boron pumps and the selection switches were in the correct configuration. The lesson learned from the event is the importance of using human performance tools such as self-checking verification, effective communication and the STAR (stop, think, act & review) principle.

Another cause of the second and third events was poor communication among the personnel involved. These two events demonstrate the need to pay attention to activities related to reactivity control and to strengthen the communication among the plant staff prior to initiating the works and/or during the activities.

The events involving unintentional or unexpected reactivity insertion have safety significance because of their potential for affecting the fuel integrity. The events described above highlight several lessons concerning the human and/or organizational factors, such as deficiencies in procedures, poor communication among the plant staff, and a lack of event information sharing. These aspects address the need to strengthen the use of human performance tools.

## 2.3. EXPERIENCE WITH CONTROL RODS

During this period, several events related to control rods were reported to the IRS. They include sticking of the control rods, failure of the control rod drive mechanism (CRDM) component, and problems with the associated components.

While the unit power was automatically reduced after a main circulation pump trip, plant operators noticed that three control rods remained in the up position. The reactor was shut down. The follow-up movement tests of the remaining control rods revealed that 22 rods were not moving. Several attempts were made to move the stuck control rods, including up-down and down-up movement, and as a result eight of them were successfully set in motion. Although 22 of 61 control rods were stuck in the upr position, the post-event analysis showed that the reactor protection system was capable of safely shutting down the reactor. The direct cause was ‘detention’ in the foreheads of the movable and immovable poles of the fixing electromagnet.

At another plant, 20 bundles of control rods from groups 1 to 6 of the control rods dropped late during the manual trip test. The metal used for the movable and immovable poles for fixing winding of the moving assembly of CRDM is martensitic alloy. The CRDM stayed in the contact state too long, resulting in the end metal surface of movable and immovable poles being bound under the effects of temperature and pressure.

In the third case, the temperature of the CRDM housing increased and exceeded the limit specified in technical specifications during restart of the reactor. The reactor was manually scrammed. Subsequent inspection revealed that the temperature increase was caused by leakage of the closed valves through which reactor coolant flowed from the upper block central venting line. The valve leakage resulted from a drifting of the closing torque switch.

The fourth instance involved the failure of two male CRDM lead screw couplings; that was discovered during maintenance. Two tangs in two separate CRDM male couplings were found to be fractured. Failure analysis of the lead screw male coupling indicated that the material had lost ductility due to thermal embrittlement. The root cause of the male coupling failures was the combination of thermal embrittlement of the pH17.4 steel and the excessive force that was used during refuelling outages when coupling and decoupling the lead screw from the control rod assembly.

**Safety significance**

Malfunction of control rods or the CRMD, in particular the sticking of multiple control rods, degrades the reactor's shutdown capability and could potentially cause the reactor not to be brought into a safe shutdown condition in a timely manner when required.

**Lessons learned**

In the first event, the root causes and contributing factors of 'sticking' of the poles' metal include inadequate testing of the operability of the control rods, resulting in prolonged contact between the metal surfaces, unclear or incomplete criteria of the manufacturer on treatment of the CRDM, causing low metal hardness and surface smoothness (exit roughness after manufacturing process). In the second event, the root causes were the number of double strokes of the CRDM not being sufficient, the metal materials, and a lack of rigidness of the poles' contact surfaces. These two events highlight the importance of carrying out the stroke test of control rods before and after they are installed at a plant.

In the third event, the prolonged temperature increase in the CRDM housing stemmed from an unsuitable ergonomic design related to signals and inadequate human–machine interface.

For the fourth event, similar plants have replaced the male couplings or revised their coupling and decoupling procedures to minimize the force applied to the male coupling, according to the vendor's recommendation. This event indicates the importance of implementing the vendor's recommendation in a timely manner.

> The sticking of multiple control rods may lead to risk significant sequences, anticipated transient without scram (ATWS). The testing and inspection of control rods and the CRDM, including pre-operational testing, should be well prepared and managed to ensure their operability and reliability. The suppliers and manufacturers should recognize the possibility of control rods sticking due to metal materials and an insufficient number of tests. Visual or other inspections can identify ageing degradation, such as cracks, which could lead to failure of the embrittled component prior to its failure. The deleterious effects can be avoided by implementing early corrective actions and monitoring and trending age related degradation.

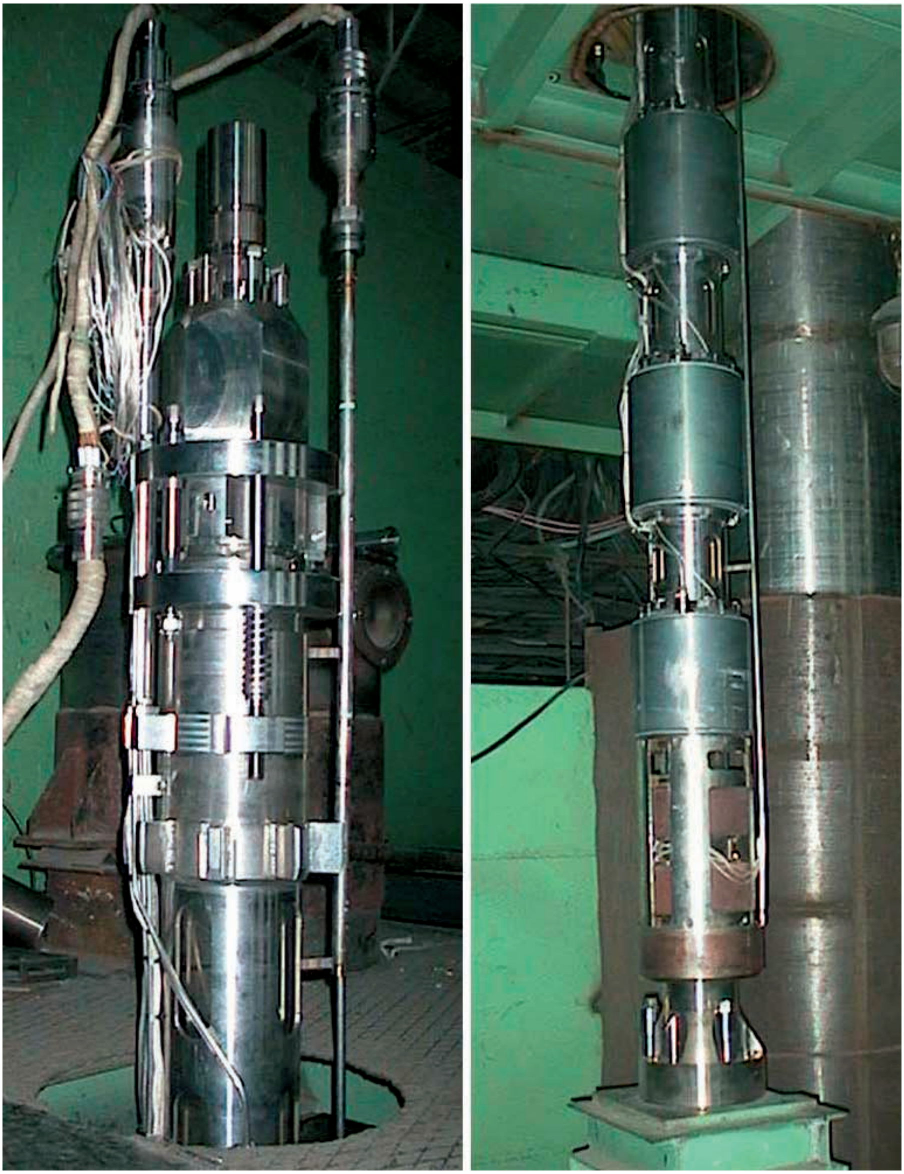

*FIG. 3. Control rod drive (source: Bulgarian Nuclear Regulatory Authority, IRS meeting 2006).*

## 2.4. EXPERIENCE WITH COMMON CAUSE

Common cause vulnerabilities continue to be reported in events. This section highlights just two such areas reported — those in emergency diesel generators (EDGs) and those in essential service water (ESW) systems.

In one event, one of the unit's four EDGs failed to start during its periodic test. The EDGs are needed to power the plant's safety related/critical equipment in case of a loss of power. Each EDG is equipped with two starter motors. The EDG did not start due to a defective rubber part in one starter motor. Upon inspection, it was discovered that five out of eight starter motors had similar defects. This component was not included in the regular maintenance programme and its safety significance had not been properly recognized.

There have been a number of events which highlight the importance of maintaining essential service water systems in a manner that precludes the development of potential common cause failure vulnerabilities due to piping or heat exchanger degradation or inadequate water chemistry controls. These events have the potential for common cause failures in a system that is the ultimate heat sink for most safety loads.

### Safety significance

Events involving the EDGs are significant, as the EDGs are safety related/critical components. In one event, a large number of safety related/critical components of the EDG starter motors were found to be defective due to a common cause that had not been identified in the regular maintenance programme. This had the potential to directly impact safe shutdown of the units.

The ESW system (or its equivalent) is the assured, safety related means of transferring decay heat from the reactor coolant system to the ultimate heat sink. The ESW system is also relied upon for other critical safety functions, such as providing cooling water for most of the essential, safety related equipment used for mitigating plant accident and transient conditions, reactor coolant pump seal cooling, spent fuel pool cooling, and for dissipating reactor decay heat during shutdown conditions. Plant specific risk assessments have shown that the loss of the ESW system may be a significant contributor to the possibility of a core damage accident.

### Lessons learned

In spite of regular maintenance and periodic testing, some faults can remain undetected. It is important for personnel to have a thorough understanding of the functioning of the plant's equipment in order to assess the safety significance of all the different components. The effects of ageing of these individual components must also be considered.

It is important to maintain ESW systems in a manner that precludes the development of potential common cause failure vulnerabilities. ESW systems may include piping sections that are buried and not readily accessible for inspection. Buried sections of piping can be subject to periodic wetting. Exterior protective coatings may also not be completely intact due to improper installation, age degradation or maintenance practices. It is important to implement an inspection programme for both internal and external corrosion.

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| Common cause vulnerabilities continue to be reported, in particular regarding EDG and ESW systems. Performing root cause analysis and implementing effective corrective actions of common cause failures are significant steps towards enhancing the safety of nuclear installations. |

## 2.5. EXPERIENCE WITH FLOODING

Flood related vulnerabilities and events have been identified at nuclear power plants around the world. Internal flooding events have been shown to be a significant contributor to risk at some facilities. Flooding events have the potential for increasing overall plant risk by making multiple trains of safety related and support equipment inoperable, and also for the added consequence of preventing or limiting operator mitigation and recovery actions. In some cases, a seemingly insignificant component (like a floor drain flow restrictor or hydrostatic barrier) could potentially impact multiple trains of safety related equipment.

In one year, at least four events were identified involving water leaking into areas containing safety related equipment due to deficient barriers or sleeves. In one event both units sustained significant damage to civil structures. At another, the water flooded into an EDG room, making the EDG inoperable. One event identified a system configuration which had not been referenced in the design basis documents.

### Safety significance

These events illustrate the importance of analysing the effect of both internal and external flooding sources, and all possible water intrusion pathways. It is important to install and maintain watertight barriers in accordance with plant design control to avoid any adverse effect on safety related equipment. In some plants, multiple trains of safety related systems necessary for safe shutdown are located at the same elevation, with potential for water intrusion into all trains. Hence the ability to achieve safe shutdown for vulnerabilities related to internal flooding events may not be ensured.

When a penetration seal functions as both a fire barrier and a flood barrier, it is important to consider both functions in the design, installation, inspection, and maintenance of the barrier. The acceptance criteria for a penetration seal to function as a fire barrier are not always sufficient to ensure its functioning as a flood barrier.

**Lessons learned**

Give priority to those attributes which are risk significant for the site specific installation, such as:

(a) Sealing of equipment below the flood line, such as electrical conduits;
(b) Holes or unsealed penetrations in floors and walls between flood areas;
(c) Adequacy of watertight doors between flood areas;
(d) Common drain system and sumps, including floor drain piping and check valves where credited for isolation of flood areas within plant buildings;
(e) Operable sump pumps, level alarms and control circuits, including maintenance and calibrations of flood protection equipment;
(f) Sources of potential internal flooding that are not analysed or not adequately maintained, for example failure of flexible piping expansion joints, failure of fire protection system sprinklers, roof leaks, rest room backups, and failure of service water lines;
(g) Condition and availability of temporary or removable flood barriers.

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| During plant baseline inspections, new reactor design reviews and subsequent inspection activities at plants under construction, personnel must be cognizant of plant areas which may be vulnerable to flooding events, particularly where a potential exists for common cause failure and/or multiple train inoperability. Often, flood protection inspections tend to focus on potential flooding sources from systems located within the room, and not from external flooding sources having an ability to migrate into the room. |

## 2.6. EXPERIENCE WITH FOREIGN MATERIAL INTRUSION

Intrusions of foreign material into the primary system and safety related systems have occasionally been reported to the IRS. These events range from minor safety consequences 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.

A foreign material intrusion event was experienced at a plant while it was undergoing periodic inspection and the reactor was shut down. During testing it was found that one control rod was near the fully withdrawn position. It was likely that during work on the operating floor near the reactor cavity a cut scrap (a mixture of iron material, concrete and paint) had flown apart and fallen between a control rod cluster guide tube and a control rod within the reactor, thus interfering with the movement of the control rod.

A second event involved a ventilation duct found at the bottom of the emergency feedwater tank. The condition of the recovered duct, uniformly covered with deposit, confirmed that it had been in the water for a long time. The duct was, however, intact and had considerable dimensions. The origin of the incident dates back to the last internal inspection when ducts were installed to ventilate the tank while a weld was repaired. A section of the duct was forgotten, most likely after the weld repair, despite the tank being inspected for cleanliness by the plant operator at the end of the repair operations.

Another event involved the discovery of a foreign material in the piping of the containment spray system during a refuelling and maintenance outage. This material was probably introduced during the preparation of a test to be performed during the outage, and it later moved to the diaphragm where it was found.

Other events showed that foreign materials were loose particles which originated internally which in some instances got stuck under the disk of check valves, preventing their functioning.

### Safety significance

The potential threat presented by foreign material is twofold. The first is the risk of pipe systems and fuel cooling paths clogging, which can result in equipment or fuel assemblies becoming overheated. The second is the risk of jamming control rods, inoperability of valves or rotating machines, resulting in degradation of reactor protection and control capabilities.

Lost particles and foreign materials can move to other parts of the system, affecting the satisfactory performance of plant critical functions.

In some cases the system was not actuated and so the event had no real consequence to the safety of the unit. Nevertheless, the obstruction caused by the presence of foreign material could have led to the partial or total unavailability of the function under accident conditions.

**Lessons learned**

Some of the above events highlight the failure of several lines of defence to operate because several layers of cleanliness work and supervisory checks had lifted hold points in the quality plan without spotting the discrepancy. It therefore demonstrates the need to monitor maintenance and overhaul operations of systems with a safety function. In some other events it was concluded that the foreign material was the result of complacent foreign material exclusion awareness, training and insufficient procedural controls.

Measures should be taken to ensure that foreign material will not spread, for example by completely covering the site when engaging in work near the reactor cavity. The measures include:

(a) Cleaning the floor surface and surface projections on the reactor cavity wall on which foreign material is likely to remain, before filling the reactor cavity with water;
(b) Carefully examining equipment and materials before transport over the reactor cavity, to ensure that no foreign material is attached to it and, when necessary, covering equipment and materials with sheets to prevent foreign material from falling;
(c) Informing employees and subcontractors of the importance of foreign material control when working near the reactor cavity or other primary systems.

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| Several IRS reports point out that intrusion of foreign material continues to occur, confirming that this issue is a recurring concern deserving more oversight both from management and regulatory bodies. Since in some cases the system was not actuated, the events had no real safety consequences. However, the presence of foreign material could have led to the partial or total unavailability of the function in an accident situation. |

*FIG. 4. Foreign material in a spray pump suction pit (source: AVN, Belgium, IRS meeting 2005).*

## 2.7. EXPERIENCE WITH HUMAN PERFORMANCE AND SAFETY MANAGEMENT

Several events were reported with multiple human errors and root causes associated with safety management weaknesses.

In one event, workers were preparing for periodic replacement of lightning protection elements in the emergency heat removal system. Because of time pressure and lack of human resources, the timing of this test had been shifted from the annual outage to the time of emergency heat removal system maintenance work during power operation. Due to violations of the test procedures and multiple errors committed during the opening of the signal path, the criteria for initiation of depressurization were fulfilled. Consequently eight of sixteen safety relief valves opened during full power operation and cold water was injected into the feedwater line.

In another event, maintenance was performed to eliminate a hot spot associated with a fuse terminal block, on the assumption that this was one of the redundant power supplies for the shutoff rods' clutch currents. Following removal of the main control room fuse, panel meters indicated that the rods had fallen into the core and that the regulating system was attempting to drive them out of the core. The redundant meters provided conflicting indications of the position and suggested that the rods had not moved from their normally poised state. Checking their position via the analog input indication suggested that the indication was irrational, and the reactor was manually shut down. Several human errors were committed during planning, verification and execution of the fuse replacement. Procedural deficiencies also contributed to the event.

**Safety significance**

The first event resulted in an unplanned transient that presented a hazard for the plant components associated with thermal shock. The measured temperature drop rates reached critical values. However, the subsequent detailed (structural, stress and fracture mechanics) analysis confirmed that stresses and strains on the critical components were within permitted ranges.

In the second event the position of the shut-off rods could not be validated due to conflicting readings and the criticality control of the reactor was jeopardized.

**Lessons learned**

These two events indicate that weaknesses in safety management and multiple human errors may lead to events with potential safety significance.

The main deficiencies in the human performance and safety management systems identified from these events are the following:

(a) Inadequate communication and reinforcement of roles and responsibilities;
(b) Lack of adequately rigorous verification;
(c) Inadequate consideration of changed conditions for tests;
(d) Deficiencies in work scheduling and human resources management;
(e) Complacency and overconfidence in the verification process in all phases of the preparation and performance;
(f) Inadequate work preparation, deficiencies in the pre-job briefing and post-job assessment;
(g) Inadequate safety principles and quality assurance in risk evaluation;
(h) Multiple violations of work instructions and procedures;
(i) Deficiencies in design and operating documentation.

The most important corrective actions were suggested to improve the communication of expectations as to roles and responsibilities, and to improve the attention of employees and management to general working and safety principles during maintenance activities.

Further corrective actions included the revision of design and operating documents, emphasizing the use of event free tools and improvement of communication in the work processes. Improvement of the quality check in the verification processes is also a very important measure.

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| In recent years, due to changes in the business environment, the management and organizational factor is becoming more important, having an impact on individual human performance as well. Management changes in the organization can have an impact on nuclear safety. Communication of clear messages from management to all levels of the organization is one of the most important pillars of good organizational culture. Long standing management problems can adversely affect nuclear safety. |

## 2.8. EXPERIENCE WITH EXTERNAL HAZARDS

Nuclear power plant systems, structures and components important to safety are designed to withstand the effects of natural phenomena like earthquakes, storms, floods, ice and global warming without any harm to the public and the power plant itself. In general, power plant sites are chosen to minimize the impact of these hazards as much as possible.

In the period 2005–2008 three events caused by earthquakes were reported. In the most severe event, a strong earthquake occurred in the vicinity of a multi-unit plant site. The actual damages from the earthquake did not affect the safe shutdown and cooling of the reactor cores. But some minor failures led to an on-site fire and the release of a small amount of radioactivity. No protective measures for the public had to be taken. The technical analysis of the earthquake impact revealed that the design acceleration values had been exceeded. The event resulted in a complete recalculation of the acceleration values to be expected due to earthquakes.

Another event occurred during the disastrous tsunami in the Indian Ocean. Thousands of kilometres from the site of the tsunami's origin, a nuclear power plant site was flooded by the unexpected high waves.

One nuclear power plant reported an all time high seawater level. The level just missed the declaration setpoint for a site emergency. Due the conservative design of the plant, no actual flooding occurred.

A plant at a riverside that is known for water level fluctuations and the forming of sand banks experienced a massive silting of the raw water intake channel. The plant decided to remove the sand from the sand trap installed in the intake water tunnel. Because there was a risk that the sand heap might become unstable during the removal operation and thus could block the entire intake, the plant operating organization introduced a specific operating instruction to cope with the situation in case of sand heap collapse. Contributing to this event was the fact that the sand had not been industrially extracted from the river for some years and the plant had not re-evaluated the potential consequences.

**Safety significance**

External hazards may lead to multiple system failures in a plant, either by flooding or mechanical loads, e.g. due to earthquakes. Because these hazards cannot be prevented, the design must take into account the challenges they pose. The vital functions of the plant — criticality control, removal of the residual heat and enclosure of the radioactivity — have to be ensured through all hazards. Special attention must be paid to environmental changes due to global warming, as well as to industrial activities in the vicinity of a plant. Tide heights, flooding by the sea as well as rivers, and draughts have to be taken into account to a greater extent than 30 years ago. Environmental changes may require backfitting measures at the plants.

**Lessons learned**

External hazards may affect power plants in various ways. The lessons learned from different events indicate a number of measures and proposals which can be used to cope with such situations. In the following, some selected generic lessons are described.

(a) Earthquakes may lead to on-site fires. Due to damage in the surrounding area of the plant, or to other commitments, external fire fighting crews might not be able to gain access. Therefore, sufficient on-site fire fighting capability should be available.
(b) Good communication and cooperation between different authorities is important. The predictions provided by, e.g. the weather service, should provide useful background information during the situation. One event emphasized the need for implementing a unified national duty system for forecasting and/or communication of extreme natural conditions and disasters.
(c) Following a tsunami incident, the regulatory body of the affected country requires tsunami events to be considered in the siting and design of existing and future nuclear facilities.
(d) Environmental conditions may change with time as the event involving silt intrusion reveals. The power plant operating organization has to analyse the effects of such changing conditions and take appropriate action well before unsafe conditions come about.

A changing environment is one of the continuous challenges of power plant operation. Close monitoring of the external conditions, in-depth analysis of events and, in case of their occurrence, good communication between the plant and the various related organizations, may help to prevent harmful effects of external hazards to nuclear power plants.

## 2.9. EXPERIENCE WITH RADIOLOGICAL CONTROL EVENTS

Radiological protection and prevention of radiological releases are major safety priorities for nuclear facilities, requiring special attention from management and all personnel. Some events during the reporting period were related to radiological releases.

In one event, periodic radiological surveillance outside the controlled area detected solid radioactive particles on-site and off-site. The particles came from the fuel building ventilation system and had been released through the ventilation stack. This system was contaminated during operations aimed at cleaning the fuel transfer channel at the end of the refuelling outage.

Another event was related to the release of tritium from the auxiliary steam system to outside the controlled area. After completion of the ultrasonic cleaning work in a condensate storage tank containing tritium, incorrect manual operation resulted in a flow path through a partially opened check valve and subsequent release to outside the controlled area.

Some other events during the period are related to unforeseen exposure of personnel.

In one of the events, while maintenance work was being carried out related to the replacement of the fuelling machine in use by one in stand-by, a heavy water spill took place. As a result, plant personnel were contaminated.

In the other event, lifting and removal of the lower internals of the reactor core was performed to allow non-destructive testing of the reactor vessel. Water plays the role of biological shielding of the irradiated structures. However, these operations require partial lifting of the lower internals above the water surface. Due to deficiencies in work planning and risk assessment, the resulting dose rate to which the personnel were exposed was very high.

### Safety significance

The results of internal activity controls in whole body counters subsequent to the particle release event showed no contamination of the persons examined. Search, removal and disposal of the particles have been laborious tasks, enhanced by using improved detection techniques. Nevertheless, associated management and communication issues make the lessons learned from the event significant.

Unforeseen personnel exposure events resulted in increased collective dose to plant personnel, and in one case a worker received a significant dose. Minimizing personnel exposure is one of the major priorities of plant operation.

**Lessons learned**

The lessons learned from the radiological release events include:

(a) Communication among different plant sections should be enhanced, either through direct contacts or at daily morning plant meetings, with information on the plant events and their safety significance being emphasized;
(b) The design adequacy of ventilation systems, radiation monitors, operating and cleaning procedures should be reviewed, as regards monitoring of incoming particles in the ventilation systems;
(c) Precautions should be established to prevent the manual startup of the normal ventilation system when conditions are not adequate;
(d) Knowledge of ventilation systems should be ensured, in particular of the existence of common ducts, their functions and operating modes;
(e) Management of tag control procedures, check sheets and communication between different teams (plant and subcontractor) should be improved.

The lessons learned from the unforeseen radiation exposure include:

(1) On time preparation and application of contingency plans;
(2) Maintenance and renewal of obsolete radiation protection equipment, as well as qualification and training of personnel in the use of protective equipment;
(3) Communication of pending maintenance tasks between operating shifts and members of the maintenance crew;
(4) Allocation of sufficient time and attention to identify and prepare critical operations concerning safety and health of personnel;
(5) Emphasizing priorities in the preparation of outages and risk management;
(6) Clearly defining roles and responsibilities of subcontractor agents in critical operations.

Several significant events evidence the need for improving the prevention and control of radiological releases and exposure of personnel. Among others, the events demonstrate the need for careful preparation of critical operations with associated risk management, and communication among different participants of information related to the plant events and their safety significance.

## 2.10. EXPERIENCE WITH DESIGN AND INSTALLATION

The reviewed events show that design deficiencies can exist for very long time periods following initial commissioning of plants. Those deficiencies may remain latent and then suddenly cause significant problems. Deficiencies in inspection and preventive maintenance programmes are important contributors to the fact that installation defects remain undetected.

Two reports during the reporting period discussed defects in the containment that are attributed to design origin.

The first report discusses the failure of one of the pre-stressing cables in the dome of the containment. Cable failures were detected during installation of the containment 13 years before this event and were corrected during the course of the installation. Four additional cable failures occurred during commercial operation of the plant. All those failures occurred when the cables were tested or maintained. The current failure was the first one to occur without any activities being performed on the cables. The failure was detected by a loud sound coming from the containment building during startup after outage.

The second containment related event involved degradation of the containment function in one plant. The failure was identified by a small amount of water leaking from the torus structure of the containment. The subsequent non-destructive examination determined that the leakage was from a small through-wall cracking that resulted in inoperability of the primary containment. The root cause analysis determined that the crack was initiated by cyclic loading due to condensation oscillation during high pressure coolant injection (HPCI) operation caused by the HPCI turbine exhaust adjacent to the affected torus wall.

In two other events, significant design errors had existed since the beginning of commercial operation of the plant with potential for significant safety consequences. In one case an error in the reactor scram breaker circuit was revealed after many years of operation of the plant. In another case a blind flange was left on backup lines of the auxiliary feedwater tank.

## Safety significance

In the first case, the failure of one cable does not result in unavailability of the safety function of the containment according to the design basis. Even simultaneous failure of two cables is allowed with some limitations on the location of the failed cables. This single failure resulted in reduction of the safety margin.

In the second event the operability of the containment was not ensured. The reactor was shut down and the torus was repaired. The exact time of the crack initiation could not be determined.

The existence of blind flange in the auxiliary feedwater tank backup line caused the long term unavailability of the backup function of the tank.

The design error in the scram breaker circuit reduced the safety margin compared to the design specification.

## Lessons learned

In the first case, the repeated cable failures during the installation and the first years of commercial operation were not adequately addressed. The corrective actions included the modification of the cable structure (diameter, number of wires in one cable, etc.), the method of installation (manufacturing, assembly and stretching technology) and improvement in the operational conditions, inspection and maintenance methodology of the cables.

The second event also involved design deficiencies and inadequate inspection methodologies. Previous operating experience for installation of a sparger to reduce stem load on the torus was not implemented. Suggested corrective actions included the improvement of the design review process and the review of the containment integrity test and inspection procedures.

The two events, with existing long term safety function degradation, highlight the deficiencies of inspection programmes in revealing long term minor errors in safety related systems.

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| Deficiencies in both component and system design can present a potential for common cause failure, resulting as a worst case in simultaneous long term unavailability of redundant safety systems. Long standing design deficiencies resulting in safety function degradation indicate the importance of the design review process and the effective surveillance and inspection programmes. Undetected design errors may cause reduced safety margins compared to the licensed conditions. |

*FIG. 5. Pre-stressing cable in a cylindrical wall — picture from the construction period (source: SUJB, Czech Republic, IRS meeting 2008).*

# 3. INSIGHTS FROM TOPICAL STUDIES AND CONFERENCES

## 3.1. TOPICAL STUDIES

Topical studies are carried out on topics of general interest where similar events may have occurred in several of the participating countries. Topical studies are organized at the yearly meeting and developed by consensus. A study usually takes two or three years to complete. The studies listed below were completed during this reporting period.

### 3.1.1. Study on analysis of cracking and corrosion issues in reactor coolant systems, 2006

Managing the safety aspects of nuclear power plant ageing requires implementation of effective programmes for the timely detection and mitigation of ageing degradation of safety related plant systems, structures, and components, so as to ensure their integrity and functional capability throughout the plant's service life.

The earliest work for this study broadly focused on IRS data where cracking and corrosion resulted in cracks, leaks, breaks, ruptures and weld failures. A preliminary analysis indicated that of the records in the IRS database, almost a third involved cracking and corrosion issues. This study also indicated that operating events affected the primary reactor systems four times more commonly than other nuclear power plant systems. Based on these first results, the topical study focuses on cracking and corrosion issues leading to primary reactor coolant failure and degradation. The report focuses on the mechanisms of degradation or failure, the root causes, and the lessons to be learned from operating experience.

The IRS database was queried to list events affecting passive components in the primary reactor systems that were caused by corrosion (listed in code along with erosion and fouling) and cracking (listed along with break, rupture, and weld failure). The key information from the IRS query was integrated with a careful selection of information from US licensee event reports (LERs) pertaining to failures, cracking, and corrosion degradation of passive components in the primary reactor systems. The reports were limited to those events that occurred from 1999 to 2005 to focus on more recent issues. Figure 6 shows the failure mechanisms from the most common (primary water stress corrosion cracking — PWSCC) to the least common. The remainder of the report provides a background and analysis of these failure mechanisms.

### 3.1.2. Study of maintenance events involving quality assurance, human factors and procedural issues, 2007

There are many examples of major events in the past years where maintenance failures were a cause or exacerbated the consequences, e.g.:

(a) Bhopal pesticide plant leak (December 1984);
(b) Japan Airlines crash (August 1985);
(c) Piper Alpha explosion (July 1988);
(d) Clapham Junction rail crash (December 1988).

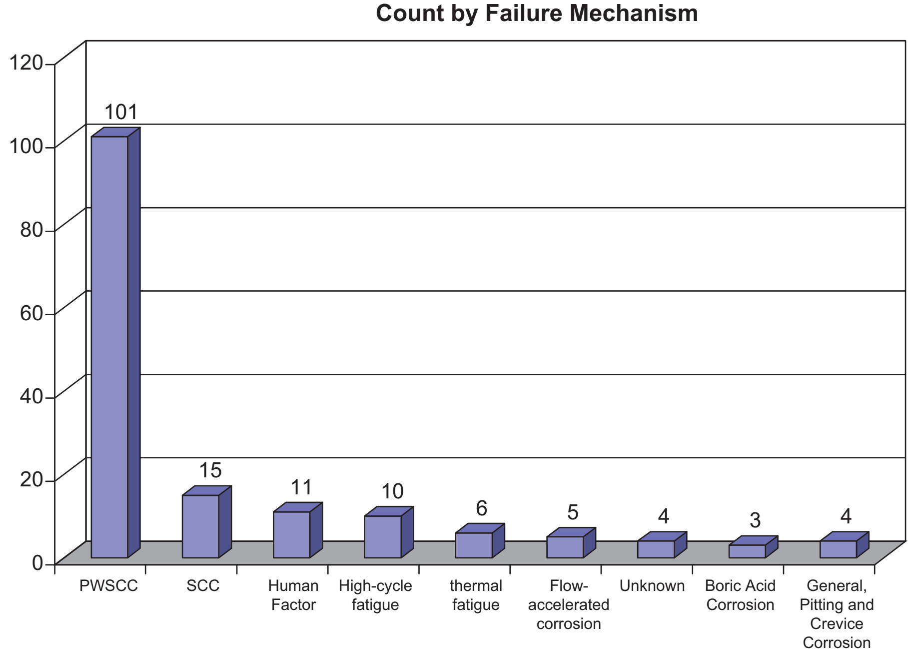


*FIG. 6. Failure mechanisms from the most (PWSCC) to the least common.*

An accident that had a major impact on the nuclear power industry occurred at a US plant, Three Mile Island, in March 1979. Two maintenance failures played a part in the accident. One actually initiated the accident and one exacerbated the situation and delayed recovery.

Latent failures had an important impact on these accidents. It must be recognized when analysing maintenance related events that the root causes of latent errors may have been introduced unintentionally during maintenance activities such as equipment repair, planned preventive maintenance, calibration, testing and inspection and that they may be revealed and lead to adverse conditions as a result of a trigger, e.g. operator action and/or the failure(s) of defences/barriers, i.e. defences which are ineffective, circumvented or missing.

Maintenance related events in nuclear power plants are a consequence of activities such as repairs, planned preventive maintenance, calibration, testing and inspection. Controls should be applied to these activities to ensure that they are performed without introducing errors. These include the preparation and use of procedures and other documents; pre-job briefings; checking and verification by individuals and peers; supervision of maintenance workers and post-maintenance testing. Failure of these controls may also lead to events.

As a consequence of improved reliability of equipment and components brought about by better materials, improved production methods and the increasing use of automated control, the balance of risk of equipment/component failure due to lack of maintenance may now be less than the risk of a healthy component being rendered ineffective as a result of ‘bad’ maintenance.

The periodic disassembly, inspection and replacement of many plant items over the lifetime of a nuclear power plant to meet the requirements laid out in the maintenance schedule provides the opportunity for human errors to occur, many of which may remain dormant, latent errors.

It is possible that latent errors now pose the greatest threat to the safe operation of complex systems such as nuclear power plants. It is therefore important that every effort be made to identify and then eliminate latent problems introduced during maintenance. The benefits of achieving this are greater than continuing to strive to eliminate active errors — however, the task is not easy.

To explore whether it is possible to reduce the frequency and severity of maintenance related events in nuclear power plants, the following questions should be considered:

(1) Which maintenance activities have historically introduced latent or occasionally active errors and consequently led to events?
(2) Which activities, if performed badly, pose the biggest risks to system safety?
(3) How often are these activities performed?

### 3.1.3. Study of operating experience on fuel handling events, 2007

Fuel handling (FH) is an essential element in the operation of nuclear power plants. This topical study helped in identifying the weak areas in FH operations at nuclear power plants that need to be addressed to eliminate events during fuel handling and to improve the safety and performance of fuel handling systems in particular, and consequently of nuclear power plants.

Performance of FH systems has improved considerably over the years due to continuous improvements made to the equipment and procedures based on the operating experience feedback from the operating plants.

Though many improvements have been made to the FH equipment to resolve problems faced over the years, there is a need to improve automation by using newer technologies such as computer based controls, particularly in view of the fact that nuclear power plants now are trying to reduce refuelling outages. Continuous upgrading of FH technology, including controls, will facilitate error free performance of tasks by operators. However, continuous vigilance over FH operations must remain a priority.

As in other areas of operations, human factors have a significant influence on the performance of FH operations. Errors in FH could have an impact on safety and availability of nuclear power plants. This requires continuous efforts on the part of nuclear power plant management to improve the quality of FH procedures and provide training to the operators. Other essential elements of human performance improvement such as pre-job briefing, proper communication and use of the STAR principle are equally applicable here.

Strict administrative controls are necessary to ensure adherence to operational procedures. Bypassing of interlocks for operational ease should be avoided. The proper authorization procedure should be followed whenever interlock bypass is required.

Improvements in ergonomic conditions, administrative procedures (such as check lists) reduce the chances of human error. Design or procedure changes based on operating feedback should be quickly implemented in all relevant plants after proper review.

Refinement of the preventive maintenance plan and replacement frequency for all critical components based on their previous performance and failure history will reduce component failure.

*Consequences and root cause events analysed in the topical study*

The events selected for the topical study were analysed by performing a detailed study of each event. The study was performed mainly to identify the root cause, its consequences and lessons learned from the event. The statistical analysis of the identified consequences and root causes are shown in Figs 7, 8:

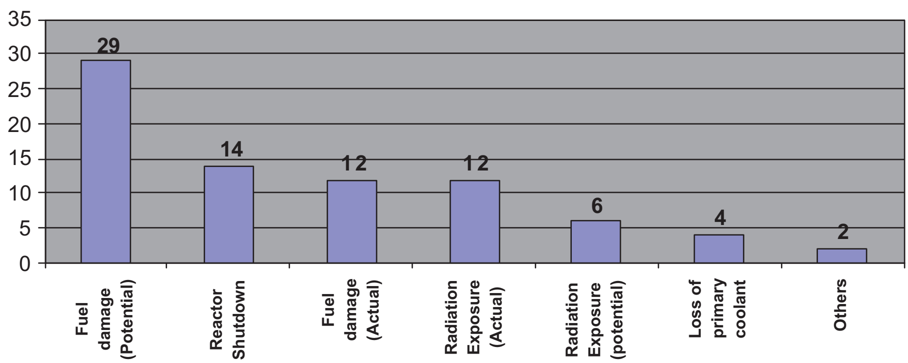


*FIG. 7. Consequences of the events.*

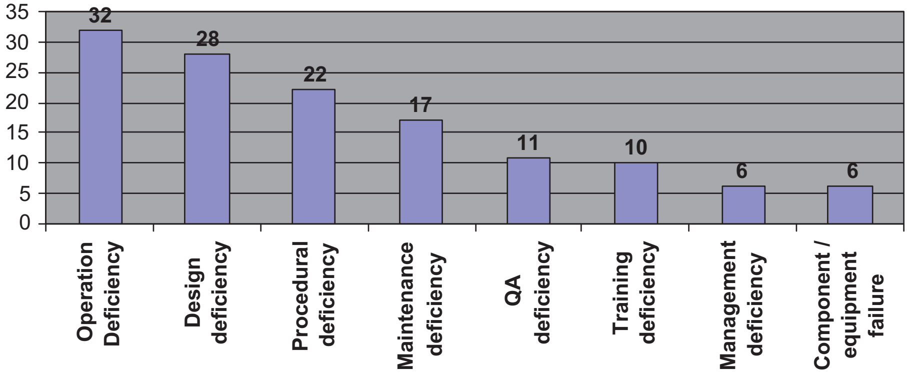


*FIG. 8. Root causes of events.*

Based on the above analysis, the following observations were made:

(a) 18% of the events resulted in actual damage to fuel. However, in 44% of the cases there was a potential for fuel damage. In reactors with shutdown refuelling, the fuel damage was mainly the result of gravity fall, which occurred due to malfunction of equipment or human error.
(b) Radiation exposure, actual or potential, to plant personnel accounts for 18% of the events.
(c) 20% of the events resulted in a loss of production in the nuclear power plant, either due to forced shutdown in on-power fuelled reactors or extension of outages in shutdown fuelled reactors.
(d) The events related to loss of primary coolant are more in on-power fuelled reactors.
(e) A major contributor (47%) to the events is human error (operation, maintenance, QA). In shutdown fuelled reactors human error has a major impact (less automation).
(f) 28% of the events are caused by organizational factors and planning such as inadequate procedures, training, management, etc.
(g) Only 5% of the events are directly attributed to component/equipment failure.

### 3.1.4. Analysis of events related to interaction between the grid and the nuclear power plants, 2008

An important event in 2006 reminded the international community that interactions between the grid and the electrical systems of nuclear power plants can be of safety significance. This event was combined with a voltage transient and several failures that worsened the consequences of the initial event. However, grid transients can challenge several electrical systems in nuclear power plants and can potentially have safety significant effects.

The scope of the study was to investigate events which are related to the interaction between the grid operating organization and the nuclear power plant operating organization.

The investigations of existing documents on operating experience show that, although valuable recommendations as related to events concerning grid interaction and the corresponding possible consequences were made, several events with similar features still occur. The first recommendation to make is thus to consider existing information and the way it was taken into account in improving electrical safety related systems in order to prevent recurrence of such events.

Some other recommendations can be made as to ways to improve the reliability of internal power supplies in case of potential grid weaknesses, or increase the independence of the internal electrical power supplies from the grid and better coordination between the grid operating organization and the nuclear power plant operating organization.

## 3.2. CONFERENCES

***IAEA conference on Operational Safety Performance in Nuclear Installations (November 2005)***

During his opening remarks the Deputy Director General asked that a few questions be kept in mind during the conference. These questions were covered during each of the four sessions.

(a) What are the links between nuclear safety management, including regulatory activities, and the global regime of continuously improving operational safety?
(b) What actions can the nuclear industry, the safety authorities and the international nuclear community take to become more proactive and to respond to early symptoms, precursors or any deviation from normal operating conditions that would help avoid events in the first place?
(c) What actions can we take to close gaps between current knowledge and human and organizational behaviour that will improve operational safety?
(d) What actions can be identified to address the issues relating to complacency? What actions can be taken regarding a questioning and learning attitude, as well as openness and transparency?

(e) How can the international nuclear community enhance sharing experiences and lessons learned regarding operating nuclear installations and how can we better reflect these lessons in the design and operation of new and evolutionary plants.

During the first session on how best to learn from and share operational safety experience and manage changes during all life cycle phases, it was pointed out that reporting of operational experience needs to be improved, and that there is evidence of not learning from OE. All organizations were encouraged to address these critical issues.

During the second session on how best to learn from and share experiences on regulatory management systems and to harmonize regulatory approaches, recommendations to develop guidelines to analyse all information/data available from operation in a systematic manner and address identified issues/trends/patterns for proactive rather than reactive response were made. Early identification of performance problems is an important element of maintaining safety.

During the third session, on how best to achieve and ensure the safety of extended operations, a major observation was the need for rapid international dissemination of best practices and operating experience and that effective knowledge management (KM) is essential. As we turn over the reins of our organizations to a new generation of regulatory bodies and operating organizations we must pass on the lessons we have learned at such a high cost. Effective KM is an essential part of this process.

During the final session, on how best to ensure that a global regime of operating experience is reflected in the design, construction, commissioning and operation of new and evolutionary reactors, it was said that many countries are taking into account operating experience in the design of new power plants. These efforts will improve safety.

***Conference on Improving Nuclear Safety through Operating Experience Feedback — Present Challenges and Future Solutions (Cologne, June 2006)***

Operating experience feedback is a key element in maintaining and improving the safety of nuclear power plant operations. It also gives impetus to the design of new plants and improved performance of existing ones. Thus the closing of the feedback loop of operating experience is of great significance to licensees, regulatory bodies, technical safety and technical support organizations (TSOs), and vendors. Recent challenges to the feedback of operating experience comprise the implications of risk informed decision making, requiring more and better statistical data to be used. Furthermore, the design of future reactors should also make optimal use of the accumulated operating experience. Nuclear energy faces more challenges in the competitive environment of today: maintaining operational safety at the highest level, cost effectiveness, high availability, event free operation and good public acceptance. An effective operating experience programme is one of the ways to address these challenges.

The IRS is an essential element for providing feedback from international operating experience for nuclear power plants. It ensures proper reporting and feedback of safety significant events for the international community, so that the causes and lessons learned can be disseminated widely. The IRS has shown that successful international operating experience feedback is possible and leads to results.

The conclusions of the conference comprise:

(1) The actions taken after events should be considered in backfitting programmes at other nuclear plants;
(2) Good practices should be identified from existing reports on operating experience to serve as examples;
(3) There is a need to exchange information with non-nuclear organizations (e.g. aviation, chemical industry, etc.) with the objective of comparing and benchmarking methods for operational experience analysis and feedback;
(4) Top management (plant managers are key people) needs to be involved and has to provide support and the resources required in addition to creating a positive attitude to operational experience analysis and feedback.

The presentations and discussions on the conference initiated the formation of the European operating experience feedback system, which started pilot operation in 2008. The IRS forms the main basis for this feedback system. The IAEA and NEA will each be represented by a member in the Advisory Board of this system. The main aim is to enforce the closing of the feedback loop by enhanced communication between the European regulatory bodies.

## 4. CONCLUSIONS

Nuclear power plant safety is not an issue that can ever be regarded as ‘fixed’. While the strong, steady safety performance of recent years is reassuring, events of concern continue to take place, even in countries with extensive operating experience and strong regulatory oversight. These events make clear that the management of nuclear safety, including the establishment of a strong safety culture for both operating organizations and regulatory bodies, must always be viewed as a ‘work in progress’. Nothing is more corrosive to continued safety performance than a belief that the safety challenge has been ‘solved’ and that attention can be focused on other matters.

Operating experience feedback is a key element in maintaining and improving the safety of nuclear power plant operations. It also gives impetus to the design of new plants and can help improve performance of existing ones. Thus, obtaining technically solid and reliable feedback on operating experience is of great significance to licensees, regulatory bodies, TSOs and vendors.

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 in order to continuously improve safety performance.

Decision makers in the industry, operating organizations and regulatory bodies around the world face a challenging environment that includes deregulation, privatization, economic pressures and fierce competition in the globalizing 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, a common safety goal.

In managing risks and resources, decision makers need credible and reliable information on nuclear systems, in particular areas of high risk, in order to prioritize their programmes. They need to receive early warning of deteriorating safety performance in the field in order to maintain an acceptable level of safety. They also need to share experience and lessons learned with others, in order to make efficient use of their resources.

Regulatory bodies require industry to report on hazards or the potential for hazards so that they can tailor effective requirements, guides or standards to limit the risks to the public.

The sharing of operating feedback is of crucial importance, for it helps in avoiding repeated failures. International bodies are providing their members with reporting systems and broad based operating feedback and history for use in trending and benchmarking. On-line sharing of operating data, outage information and corrective actions can be further advanced.

The IRS is one of the most important elements of operational safety in the operating experience feedback processes that take place at both the national and international levels. In providing the world’s safety experts and managers with information on individual and generic issues of safety significance the IRS, together with other systems, contributes to prioritize issues important to safety and assists in the identification of areas in which further resources or research is appropriate.

This fourth publication, for the period 2005–2008, highlights important lessons learned from events reported to the IRS over that period and provides senior safety managers and staff members, in regulatory bodies and in industry, with information related to safety of nuclear power plants to help them in their decision making roles.

About 220 events have been reported by the participating countries during the period and several among them, as well as generic issues, were selected in this report to show the range of important topics reviewed during the period by the national IRS coordinators.

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

Recently, the International Nuclear Safety Group published their 23rd report, entitled Improving the International System for Operating Experience Feedback.

The International Nuclear Safety Group (INSAG) is a group of experts with high professional competence in the field of nuclear safety, working in regulatory organizations, research and academic institutions and the nuclear industry. INSAG is constituted under the auspices of the IAEA with the objective of providing authoritative advice and guidance on nuclear safety approaches, policies and principles for nuclear installations (defined as nuclear power plants, fuel cycle facilities, research reactors and support facilities). In particular, INSAG provides recommendations and informed opinions on current and emerging nuclear safety issues to the international nuclear community and public.

The main recommendations of the report are the following:

(a) Current international OEF processes need to be further developed within the framework of the Global Nuclear Safety Regime. To achieve this objective, the international OEF system should be supported by an internationally agreed mechanism for coordination and guidance. A possible vehicle to address this need is a high level international advisory group of recognized experts.
(b) Countries operating nuclear facilities should improve transparent sharing of information relating to nuclear safety, both nationally and internationally, consistent with the spirit of the Convention on Nuclear Safety.

(c) Increased resources need to be allocated, both nationally and to international organizations, to make international OEF systems more effective and efficient. This should result in more comprehensive reporting, in higher quality reports and in more effective utilization of the received reports.

# ABBREVIATIONS

| | |
|---|---|
| ATWS | Anticipated transient without scram |
| BWR | Boiling water reactor |
| CRDM | Control rod drive mechanism |
| EDG | Emergency diesel generator |
| ERG | Event review group |
| ESW | Essential service water |
| FH | Fuel handling |
| FME | Foreign material exclusion |
| HCPI | High pressure coolant injection |
| INES | International Nuclear and Radiological Event Scale |
| INSAG | International Nuclear Safety Group |
| KM | Knowledge management |
| LER | Licensee event reports |
| PWR | Pressurized water reactor |
| STAR | Stop, think, act and review |
| TSO | Technical support organization |
| UPS | Uninterrupted power supply |

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Incident reporting has become an increasingly important aspect of the operation and regulation of all public health and safety-related industries. The International Reporting System for Operating Experience is an essential element of the international operating experience feedback system for nuclear power plants. The IRS is jointly operated and managed by the OECD Nuclear Energy Agency (OECD/NEA), a semi-autonomous body within the Organisation for Economic Co-operation and Development (OECD), and the IAEA.

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