SOER
(WANO - Significant Operating Experience Report)
methodology and analysis

by

Ir. René Lauwers

A thesis submitted in partial fulfilment of the
requirements for the degree of

Master of Science in Nuclear Engineering
BNEN – University of Ghent

2008 – 2009

Promoter:     Prof. Dr. Ir. W. Van Hove
Assessors:    Prof. Dr. Ir. W. D’haeseleer
              Prof. Dr. Ir. P. -E. Labeau
Mentor:       Ir. Sven Van den Sande

Academic Year 2008-2009

Belgian Nuclear Higher Education Network, c/o SCK•CEN, Boeretang 200, BE-2400 Mol, Belgium
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List of abbreviations used

AGR : Advanced gas cooled reactor
CPTE : Company for Coordination of Production and Transport of Electrical Energy
CRDM : Control Drive Mechanism
DPRK : Democratic People’s Republic of Korea
ECB : Estimated Critical Boration
EOC : End Of Cycle
GSU : Generator Step up
HU : Human Performance
IAEA : International Atomic Energy Agency
IGV : Inlet Guide Vanes
INPO : International Nuclear Power Operations
JIT : Just In Time
MELLA : Maximum Extended Load Line Limit Analyses
MEOD: Maximum Extended Operating Domain
NPP : Nuclear Power Plant
NPT : Non Proliferation Treaty
PI : Performance Indicators
PPM : Process and Performance Management
RCM : Reliability Centered Maintenance
RCS : Reactor Coolant System
RHR : Residual Heat Removal
RPV : Reactor Pressure Vessel
SAR : Safety Assessment Review
SCRAM : Super-Critical Reactor Axe Man or Super Critical Reaction Abatement Mechanism
SER : Significant Event Report
SOER : Significant Operating Experience Report
WANO : World Association of Nuclear Operators
1 INTRODUCTION AND PROBLEM STATEMENT

After the accident at the Chernobyl nuclear power plant in 1986 (see appendix 1), nuclear operators world-wide realised that the consequences had an effect on every nuclear power plant and international cooperation was needed to ensure that such an accident can never happen again.

WANO (World Association of Nuclear Operators) was formed in May 1989 by nuclear operators world-wide uniting to exchange operating experience in a culture of openness, so members can work together to achieve the highest possible standards of nuclear safety.

The culture of openness allows each operator to benefit and learn from others’ experiences, challenges and best practice, with the ultimate goal of improving nuclear plant safety, reliability and performance levels for the benefit of their customers throughout the world.

One of the means of promoting this exchange of others experiences is the establishment of SOER's (Significant Operating Experience Reports) which give for significant incidents an overview of the issues that could occur in Nuclear Power Plants (NPP's) based upon real events. These SOER's need to be analysed by each member Power Plant, a gap analysis needs to be done and an action plan has to be established to answer to the issues involved in the SOER.

The aim of this dissertation is to make an evaluation of the different methodologies for analysing SOER's based on the review of the analyses done by NPP Doel in the past of the following SOER’s :

- SOER 1998-1 : Safety system status control
- SOER 1999-1 : LOSS OF GRID inc 2004 Addendum
- SOER 2001-1 : Unplanned Radiation Exposures
- SOER 2002-1 : Severe weather
- SOER 2002-1 : Emergency Power Reliability
- SOER 2003-1 : Power Transformer Reliability
- SOER 2003-2 : Reactor Pressure Vessel Head Degradation
- SOER 2004-1 : Managing Core Design Changes

A comparison will be made regarding the minimal requirements for analysis of these SOER’s as demanded by WANO, and the analyses done by the NPP Doel will be challenged with the
recommendations to verify if the original analysis is compliant to the recommendations of the SOER's.

Thus the best reviewing method will be chosen.

A recent report will be analyzed in more detail using the best methodology: the SOER 2007-1 regarding reactivity management which has to be analyzed by Electrabel, NPP Doel.
2 INTERNATIONAL NUCLEAR ORGANISATIONS AND ELECTRABEL

2.1 INTRODUCTION

As mentioned before, Electrabel is a member of the international organizations WANO and INPO (International Nuclear Power Operation). Being member of these organizations implies several commitments which are mandatory.

In this chapter a brief overview of the most important international organizations will be presented. This overview will be presented in the chronological order of establishment of these organizations.

Further a more detailed explanation will be given regarding the SOER’s, their purpose and content and a short description of the present organization of Electrabel and of the NPP Doel.
2.2 IAEA – INTERNATIONAL ATOMIC ENERGY AGENCY.

The texts mentioned in this chapter which are in italic and between brackets are taken from the following website: www.iaea.org

2.2.1 History

“The IAEA was created in 1957 in response to the deep fears and expectations resulting from the discovery of nuclear energy. Its fortunes are uniquely geared to this controversial technology that can be used either as a weapon or as a practical and useful tool.

The Agency's genesis was US President Eisenhower's "Atoms for Peace" address to the General Assembly of the United Nations on 8 December 1953. These ideas helped to shape the IAEA Statute, which 81 nations unanimously approved in October 1956. The Statute outlines the three pillars of the Agency's work

- nuclear verification and security
- safety
- technology transfer.

In the years following the Agency's creation, the political and technical climate had changed so much that by 1958 it had become politically impracticable for the IAEA to begin work on some of the main tasks foreseen in its Statute. But in the aftermath of the 1962 Cuban missile crisis, the USA and the USSR began seeking common ground in nuclear arms control.

In 1961 the IAEA opened its Laboratory in Seibersdorf, Austria, creating a channel for cooperative global nuclear research. That year the Agency signed a trilateral agreement with Monaco and the Oceanographic Institute headed by Jacques Cousteau for research on the effects of radioactivity in the sea, an action that eventually lead to the creation of the IAEA's Marine Environment Laboratory.

As more countries mastered nuclear technology, concern deepened that they would sooner or later acquire nuclear weapons, particularly since two additional nations had "joined the club", France in 1960 and China in 1964. The safeguards prescribed in the IAEA's Statute, designed mainly to cover individual nuclear plants or supplies of fuel were clearly inadequate to deter proliferation. There was growing support for international, legally binding commitments and comprehensive safeguards to stop the further spread of nuclear weapons and to work towards their eventual elimination.
This found regional expression in 1968, with the approval of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) (see appendix 2). The NPT essentially freezes the number of declared nuclear weapon States at five (USA, Russia, UK, France and China). Other States are required to forswear the nuclear weapons option and to conclude comprehensive safeguards agreements with the IAEA on their nuclear materials.

The 1970s showed that the NPT would be accepted by almost all of the key industrial countries and by the vast majority of developing countries. At the same time the prospects for nuclear power improved dramatically. The technology had matured and was commercially available, and the oil crisis of 1973 enhanced the attraction of the nuclear energy option. The IAEA's functions became distinctly more important. But the pendulum was soon to swing back. The first surge of worldwide enthusiasm for nuclear power lasted barely two decades. By the early 1980s, the demand for new nuclear power plants had declined sharply in most Western countries, and it shrank nearly to zero in these countries after the 1986 Chernobyl accident.

The Three Mile Island accident (see appendix 3) and especially the Chernobyl disaster (see appendix 1) persuaded governments to strengthen the IAEA’s role in enhancing nuclear safety.

In 1991, the discovery of Iraq’s clandestine weapon programme sowed doubts about the adequacy of IAEA safeguards, but also led to steps to strengthen them, some of which were put to the test when the Democratic People’s Republic of Korea (DPRK) became the second country that was discovered violating its NPT safeguards agreement.
In the early 1990s, the end of the Cold War and the consequent improvement in international security virtually eliminated the danger of a global nuclear conflict. Broad adherence to regional treaties underscored the nuclear weapon free status of Latin America, Africa and South East Asia, as well as the South Pacific. The threat of proliferation in some successor States of the former Soviet Union was averted; in Iraq and the DPRK the threat was contained.

In 1995, the NPT was made permanent and in 1996 the UN General Assembly approved and opened for signature a comprehensive test ban treaty. While military nuclear activities were beyond the IAEA's statutory scope, it was now accepted that the Agency might properly deal with some of the problems bequeathed by the nuclear arms race

- verification of the peaceful use or storage of nuclear material from dismantled weapons and surplus military stocks of fissile material
- determining the risks posed by the nuclear wastes of nuclear warships dumped in the Arctic
- verifying the safety of former nuclear test sites in Central Asia and the Pacific.

In recent years, the Agency’s work has taken on some urgent added dimensions. Among them are countermeasures against the threat of nuclear terrorism, the focus of a new multi-faceted Agency action plan."  

2.2.2 Mission of IAEA

“The IAEA works for the safe, secure and peaceful uses of nuclear science and technology. Its key roles contribute to international peace and security, and to the World’s Millennium Goals for social, economic and environmental development.

Three main pillars - or areas of work - underpin the mission

Safeguards and supervision: The IAEA is the world's nuclear inspectorate, with more than four decades of verification experience. Inspectors work to verify that safeguarded nuclear material and activities are not used for military purposes. The Agency is additionally responsible for the nuclear file in Iraq as mandated by the UN Security Council.

Safety and security: The IAEA helps countries to upgrade nuclear safety and security, and to prepare for and respond to emergencies. Work is keyed to international conventions, standards and expert guidance. The main aim is to protect people and the environment from harmful radiation exposure.

Science and technology: The IAEA helps countries mobilize peaceful applications of nuclear science and technology. The work contributes to goals of sustainable development in fields of
energy, environment, health, and agriculture, among others, and to cooperation in key areas of nuclear science and technology.”

More information can be found on the website: www.iaea.org

2.3 INPO – INSTITUTE OF NUCLEAR POWER OPERATIONS

The texts mentioned in this chapter which are in italic and between brackets are taken from the following website: www.inpo.info

“The Kemeny Commission – set up by President Jimmy Carter to investigate the March 1979 accident at the Three Mile Island nuclear power plant (see appendix 3) – had recommended that:

“The (nuclear power) industry should establish a program that specifies appropriate safety standards including those for management, quality assurance, and operating procedures and practices, and that conducts independent evaluations.”

There must be a systematic gathering, review and analysis of operating experience at all nuclear power plants coupled with an industry-wide international communications network to facilitate the speedy flow of this information to affected parties.

In addressing those recommendations, the nuclear power industry:

- Established INPO – the Institute of Nuclear Power Operations
- Charged INPO with a mission that remains the same today:

To promote the highest levels of safety and reliability – to promote excellence – in the operation of nuclear electric generating plants.

All U.S. organizations that operate commercial nuclear power plants are INPO members. Nuclear operating organizations in other countries and nuclear steam supply system, architect/engineering and construction firms can be INPO participants.

INPO Institute of Nuclear Power Operations - Insight and Integrity
The National Academy for Nuclear Training, which operates under the auspices of INPO, embodies the U.S. commercial nuclear utility industry’s commitment to high quality training and professionalism. The Academy integrates the training related efforts of nuclear utilities, the independent National Nuclear Accrediting Board and the Institute’s training activities. INPO also represents U.S. utilities in the World Association of Nuclear Operators- Atlanta Centre. WANO is an international organization that unites nuclear electric power plants to facilitate the exchange of information worldwide.
INPO has several technical programs:

- Evaluations
- Training and accreditation
- Events analysis and information exchange
- Assistance

2.3.1 EVALUATIONS

“The performance-based operating plant evaluation has been a key activity to support INPO’s mission since its beginning in 1979. In these evaluations, teams of Institute and utility personnel compare plant performance to standards of excellence based on experience and best practices. INPO also conducts review visits in selected areas to supplement the evaluation program.”

2.3.2 TRAINING AND ACCREDITATION

“INPO supports member utilities in their work to provide high quality training for utility personnel and maintain accreditation of training programs. These interactions include evaluating accredited training programs to verify that the standards for accredited training programs are maintained. In addition, the National Academy for Nuclear Training conducts a variety of training courses and seminars for nuclear plant personnel each year to foster increased professionalism and performance.”

2.3.3 EVENTS ANALYSIS AND INFORMATION EXCHANGE

“Events analysis programs identify and communicate lessons learned from plant events so utilities can take action to prevent similar events at their plants. INPO also operates an extensive computer network through which members and participants electronically exchange information in areas such as plant operations, maintenance, operating experience and equipment reliability.”

2.3.4 ASSISTANCE

“INPO helps members improve nuclear operations through assistance programs that continually evolve to meet the changing needs of the nuclear industry. Through assistance visits, working meetings, workshops, technical documents and loan of personnel, INPO fosters comparison and the exchange of successful methods among members.”

More information can be found on the following public website: [www.inpo.info](http://www.inpo.info)
2.4 WANO – WORLD ASSOCIATION OF NUCLEAR OPERATORS

2.4.1 Purpose of WANO

The texts mentioned in this chapter which are in italic and between brackets are taken from the following website: www.wano.org.uk

“The World Association of Nuclear Operators is an organization created to improve safety at every nuclear power plant in the world. After the accident at the Chernobyl nuclear power plant in 1986 (see appendix 1), nuclear operators world-wide realised that the consequences had an effect on every nuclear power plant and international cooperation was needed to ensure that such an accident can never happen again.

WANO was formed in May 1989 by nuclear operators world-wide uniting to exchange operating experience in a culture of openness, so members can work together to achieve the highest possible standards of nuclear safety.

The mission of WANO is:

To maximise the safety and reliability of the operation of nuclear power plants by exchanging information and encouraging communication, comparison and emulation amongst its members.

The culture of openness allows each operator to benefit and learn from others’ experiences, challenges and best practice, with the ultimate goal of improving nuclear plant safety, reliability and performance levels for the benefit of their customers throughout the world.

As every organisation in the world that operates a nuclear electricity generating plant is a member of WANO, it is a truly international organisation, cutting across political barriers and interests. WANO is an association set up purely to help its members achieve the highest practicable levels of operational safety, by giving them access to the wealth of operating experience from the world-wide nuclear community. WANO is non profit making and has no commercial ties. It is not a regulatory body and has no direct association with governments. WANO has no interests other than nuclear safety. WANO seeks to assist members through its programmes of work (see §2.4.3):

- Peer Reviews
- Operating Experience
- Technical Support and Exchange
- Professional and Technical Development
When a WANO member participates in a WANO activity, they know that they will have highly experienced teams of experts from other nuclear power plants to help them improve safety and reliability at their own power plant.

Since the inaugural meeting in May 1989, WANO has worked to support each member in their quest for ‘operational excellence’ by helping to prevent events; minimising downturns in performance and improving overall plant operations – thereby fulfilling the WANO mission of ‘maximising safety and reliability’. It is recognised that safe, reliable operation will increase productivity. WANO reports are available in printed form and via the comprehensive secure Web site that is restricted to its members. The Web site also allows sharing of information.

WANO members report events via the secure Web site to share experience and lessons learned. The WANO Operating Experience Central Team reviews all member reports and prepares Significant Operating Experience Reports (SOERs) or Significant Event Reports (SERs) and Just-in-Time briefings to address important topics.

Peer Review pages describe how peer reviews are conducted and contain the Performance Objectives and Criteria used for peer reviews.

There are summary reports from previously held workshops and seminars, such as ‘Conservative Decision Making’, ‘Materials’ and ‘Outage Management’.

Good Practices identify techniques, programmes or processes that have been proven particularly effective at improving safety and reliability and cover all the key nuclear disciplines, including operations, maintenance, radiological protection and training. There are also comprehensive Guidelines to help members to achieve excellent performance across a range of activities.

The Performance Indicator programme provides a quantitative indication of nuclear plant performance in the areas of nuclear plant safety, reliability and personnel safety. A printed report is published annually to show safety trends and are available on this Web site.

The WANO Network Forum enables members to pose questions via the Web site to receive responses from members at nuclear power plants anywhere in the world.

A magazine ‘Inside WANO’ is printed three times a year and is available on the public Web site.

The WANO Review is printed biennially and distributed to its members.
2.4.2 Organisation of WANO

“The organisation of WANO is deliberately uncomplicated. WANO’s work is largely carried out by its members, while the WANO staff, whose main role is to facilitate the running of WANO’s programmes, is kept small to avoid unnecessary bureaucracy. Care is taken to ensure that members are well represented in the policy making governing boards of WANO.

Membership of WANO is through one or more of its four regional centres, Atlanta, Moscow, Paris and Tokyo, and is determined by geographical location or reactor type. There is also a coordinating centre in London. The regional centres carry out the WANO Governing Board’s decisions and organise WANO’s programmes. Much of their work involves collecting, screening and analysing operating information before sending it to members and ensuring WANO programmes meet member needs.

Each regional centre has a director and highly experienced staff seconded from member organisations for two to four years. Secondees bring specific plant knowledge and an understanding of their own country’s operating culture to the WANO centres. In turn they take back to their own organisations broad experience obtained from working at the centres and an insight into other members’ operations.

The regional centres are semi autonomous, with their own regional governing boards, but they work closely together as a team to ensure exchange of ideas and consistent implementation of WANO policies.

Every two years senior executives of all members are given the opportunity to meet at a Biennial General Meeting to review progress and provide guidance for the future aims and objectives of WANO. At each Biennial General Meeting a WANO President is elected. This is an honorary position with a two year term.

A central Governing Board provides the overall direction of WANO and establishes WANO policies. It is made up of an elected chairman and two representatives from each Regional Governing Board. The directors of the WANO centres also attend the meeting. This board meets three times a year. The WANO Chairman is elected for a two year term, which can be renewed once.”
A list of the current members of WANO can be found in appendix 4. This information can also be found on the public website of WANO. (www.wano.org.uk)

2.4.3 Programmes of WANO

WANO has four main programmes:

- Operating experience
- Peer reviews
- Professional and Technical Development (Workshops & Seminars)
- Technical Support and Exchange (comprising Good Practices, Performance Indicators, Operator Exchanges, and Technical Support Missions)

2.4.3.1 Operating Experience

“This programme enables WANO members to learn from each others’ experiences. In particular, it alerts members to events that have occurred at other plants and enables them to take action to prevent similar events from happening at their own plants. In participating in this
programme, members willingly share information for the benefit of other nuclear operators throughout the world.

Through this programme, members report on “events” that have occurred at their plants. An “event” is defined as any significant deviation from the normal expected functioning of a plant. When an event occurs, the affected plant management and staff analyse the event and complete an “event report”, which is sent to the member’s WANO Regional Centre.

To ensure that the information exchanged is valuable to its members, WANO has established specific reporting information categories, including causes, corrective actions and learning points. Events may involve, for example, equipment damage or a significant plant transient. In other cases, an event report may reveal flaws in construction, design, operating methods, human performance, maintenance or training. Members are encouraged to report events promptly, so that others can benefit from their experience.

The Operating Experience Central Team conducts analysis of events occurring at member plants. This team monitors events across WANO to identify significant issues. Based on the number and significance of events, the Operating Experience Central Team writes SOERs (Significant Operating Experience Reports), SERs (Significant Event Reports) or JITs (Just-in-Time briefings). These reports warrant focused member attention and provide analysed information and learning points that can be applied across all plant types.

SERs and SOERs are produced when an event is considered to be of sufficient importance to other nuclear plants around the world. The reports and the training materials are used to take appropriate corrective actions and relay pertinent information to the plant staff.

Just-in-Time briefings are for the benefit of workers and their supervisors. The Experience Team analyse and condense industry experience into JIT briefing sheets to assist workers when they prepare for particular tasks. Whether preparing to conduct post-maintenance testing or radiation surveys, the operating experience of others is available on the secure WANO members’ Web site.”

2.4.3.2 Peer reviews

“This programme aims to help WANO members compare their operational performance against best international practice through an in-depth, objective review of their operations by an independent team from outside their utility. The review, carried out at the request of the plant, is conducted by an international team consisting of staff from other nuclear power plants, in other words, peers of the staff of the station reviewed. The team examines the plant’s performance in key areas in accordance with specific performance objectives and criteria.
WANO peer reviews give members an opportunity to learn and share the best worldwide insights into safe and reliable plant operation, and thereby improve their own performance.

The WANO peer review programme began in 1991 at the request of members. Pilot peer reviews took place in 1992 and 1993. Following the success of eight pilot peer reviews, the voluntary WANO Peer Review Programme was formally adopted in 1993.

In a peer review, a WANO team is invited by a utility to spend two weeks at their plant observing plant activities and materiel condition, conducting interviews and reviewing performance-related documentation. A typical peer review examines the plant’s performance in the following areas:

- Organisation and Administration
- Operations
- Maintenance
- Engineering Support
- Radiological Protection
- Operating Experience

In addition, members often request the following additional areas to be included in the peer review:

- Training and Qualification
- Emergency Preparedness
- Chemistry
- Fire Protection

Cross-functional areas, which are also reviewed, apply to the entire workforce. These include:

- Safety Culture
- Human Performance
- Self-valuation
- Industrial Safety
- Plant Status and Configuration Control
- Work Management
- Equipment Performance and Condition

All areas are reviewed in accordance with the WANO Performance Objectives and Criteria.
The review team consists of highly qualified staff from other WANO members throughout the world who have extensive experience in the areas they review. They bring together the knowledge and experience of operating plants in different countries, and make an objective assessment of the operations of the plant against best international practices. During the review, the team notes strengths that may be useful to other plants, and areas in which improvements can be made to enhance safety and reliability at the plant. The team focuses on observing day-to-day activities and the material condition of the plant. The result is a confidential report to the utility identifying strengths and areas for improvement. This confidentiality ensures full, open discussion between the review team and the management of the plant reviewed. Members of the team also benefit from the review process by taking good ideas and practices back to their own plants.

WANO members, with their own established review programmes as internal/external audits, may choose to replace one of their evaluations or reviews with a WANO peer review. This approach allows them to satisfy their existing requirements and also benchmark their performance within the international nuclear community.

WANO members participate in the peer review programme through the following activities:

- Hosting peer reviews
- Providing peers for review teams
- Emulating good practices identified during peer reviews
- Taking actions to address areas for improvement as a result of a peer review
- Using programme resources such as the WANO Performance Objectives and Criteria, “How To” documents and industry wide areas for improvement
In early 2000, WANO met a long-term goal by completing a peer review at 50 percent of all sites worldwide. As more peer reviews are conducted, the knowledge of their benefits is becoming more widespread, and more plants are asking to host peer reviews. Since 1992 WANO have conducted 358 peer reviews in 32 countries. 196 out of 198 operating nuclear stations worldwide hosted at least one peer review.” Specifically, NPP Doel has already hosted 4 WANO Peer Reviews.

2.4.3.3 Workshops & Seminars

“Through the WANO Professional and Technical Development Programme, members can meet other workers from around the world to exchange information and ideas for improving the safety and reliability of nuclear power plants. Workshops, seminars, expert meetings and training courses provide a forum for plant staff to increase their professional knowledge and skills. These activities enable members from all regions to compare their operations and emulate best practices, leading to improved operational performance.

Attendance at workshops, seminars, courses and expert meetings is open to all WANO members. Typically they are organised as a result of member demand or to address areas of common interest or concern that emerge during other WANO programmes. Special care is
taken to ensure that these interactions are of high quality and that they focus on areas of
greatest interest and need.

Members from all regions are invited to attend meetings to provide a wide range of knowledge
and discussion. There is no meeting fee. Normally, all meetings are held in English, but in
some cases, they can be held in other languages depending on the profile of participants.
Most are hosted by a member, and are organised by one of the Regional Centres in close
cooperation with that member.”

2.4.3.4 Technical support and exchange

2.4.3.4.1 Good Practices

“This activity aims to identify good practices used by members and to bring them to the
attention of other members, so that they can learn from each other’s best practices to improve
operational safety and reliability. A good practice is a technique, programme or process that
has been proven particularly effective at improving safety and reliability at one or more nuclear
power plants. Once identified and screened for applicability and genuine value to other plants,
good practices are distributed to members via the members’ secure WANO Web site, a good
practice database and an annual report.

In addition, a new series of support documents, WANO Guidelines, have been developed for
each functional area to help members to achieve excellent performance.”

2.4.3.4.2 Performance indicators

“A set of performance indicators has been developed to enable members to exchange
information and assess the performance of their plants objectively. With each member
providing data on its performance, WANO members can compare their performance with that
of other plants around the world. Performance indicators are mainly used as a management
tool so each member can monitor its own performance and progress, set challenging goals for
improvement and consistently compare performance with that of other plants or the industry.

The indicators give a quantitative indication of nuclear plant safety and reliability, plant
efficiency and personnel safety. WANO members report on most of these indicators for each
nuclear unit on a quarterly basis. The data is collected through the secure WANO members’
Web site, trended and posted on the WANO members’ Web site. Experience has shown that
using performance indicators can contribute to significant improvements in plant performance.
“Current worldwide performance indicators are published annually, including historical trends, in a WANO Performance Indicator Tri-fold Report (see appendix 5).

2.4.3.4.3 Operator exchanges

“This activity enables members to directly share plant operating experience and ideas for improvement through face-to-face communication. It lets members from all WANO regions compare their operations and emulate each other’s best practices, which leads to improved operational performance. Contact between nuclear power plant staff is largely in the form of operator exchange visits, twinning’s and the exchange of personnel. It also includes the exchange of documentation and other cooperation between operating organisations.

Operator Exchanges are visits of staff from one plant to another. Participants are normally directly involved with plant operations, and the information exchange is open and frank. The visits provide an opportunity for staff to observe different approaches to their work which enables them to reconsider their own practices. The visits address all aspects of plant operations such as operations, maintenance, training, radiological protection, organisation and administration, chemistry, quality assurance and emergency planning.
Several exchanges between plants have turned into long-term relationships known as twinning’s. Typically, these relationships involve ongoing information exchanges, visits, a deeper cooperation and, in some cases, exchanges of technology and personnel.”

2.4.3.4.4 Technical support missions

“These involve the cooperation between members to provide mutual help and support to each other in a practical and focused form. This activity involves members helping each other to identify solutions to known problems at nuclear power plants. They are conducted at the request of a member to their Regional Centre, which organises the mission.

Technical support missions consist of a small team of experienced nuclear staff from other members, who apply their experience to propose solutions to problems, or areas for improvement previously identified through self-evaluation or WANO peer reviews.

Technical support missions have been requested for a variety of areas, such as outages, on-line maintenance, radiation protection and waste management. At the end of a mission, the team briefs the host member, giving suggestions or solutions for resolving the original problem.”

2.4.4 Publications

Several publications are made by WANO which are public. These include:

- **Inside WANO** is the magazine issued three times a year covering information and technical articles about WANO and the work of WANO members. It is produced in six languages, English, French, German, Japanese, Russian and Spanish.
- The **WANO Review** is produced biennially to coincide with the Biennial General Meeting.
- The **WANO map** is a wall poster which gives an overview of the nuclear power plants which are member of WANO.
- The **Performance Indicator** (PI) Tri-fold gives facts and figures showing safety performance trends.
2.5 SOER – SIGNIFICANT OPERATING EXPERIENCE REPORT

2.5.1 Purpose of a SOER

An SOER or Significant Operating Experience Report groups a number of important events that happened in nuclear power plants over the world, with cause and effects. These reports are established by WANO and made available to its members. It is mandatory for each member to analyse the SOER. The analysis should comprise of the following:

For each aspect mentioned in the SOER, the nuclear power operator must verify if the aspect is applicable to his power plant. This analysis and verification must be reported to WANO.

If aspects of the SOER are applicable to the nuclear power operator, the proposed recommendations by WANO must be analysed and evaluated by the power operator. The power operator will have to implement the recommendations in his own power plant with an action plan or he can establish an alternate solution that still complies with the initial recommendation.

WANO conducts a follow up of the analysis of the SOER in each power plant and during periodic Peer reviews the action plan of the SOER which has been established by the power operator is evaluated with regards to quality and progress.

2.5.2 Summary of existing SOER’s within WANO

WANO has established since its foundation 11 SOER’s, which are updated in the course of time if new events happened. Hereunder the SOER’s are mentioned with a short summary.

The SOER nomenclature is as follows: SOER “year” – “Index” : “Title”.

The year refers to the year of first appearance of the SOER, the index refers to the sequence number of SOER that appeared in that year, and then the title of the SOER is mentioned.

2.5.2.1 SOER 1998-1 : SAFETY SYSTEM STATUS CONTROL

This SOER was written because between 1996 and 1998 at least 10 events happened with regard to the loss of safety system status in several WANO member plants. These events happened mostly after an outage for refuelling and maintenance activities. These events can result in loss of safety system functions which reduce margins to nuclear safety. The safety system functions are one of the barriers used in the “defence in depth” strategy to ensure...
nuclear safety. During outage and post-outage start up, a lot of interventions are done on the safety systems, and proper testing of the safety systems before start-up is necessary to ensure their functioning during operation of the nuclear power plant. This WANO SOER and its recommendations are reminders of the great diligence required during these periods if adverse impacts on safety system availability are to be avoided.

2.5.2.2 SOER 1999-1: LOSS OF GRID inc 2004 Addendum

This SOER deals with the effects of loss of grid and thus loss of off-site power, which can have an effect on functioning of safety systems and on the core damage frequency. Between 1997 and 1999 more than 25 events have occurred involving loss of grid or degraded grid conditions. This SOER deals with how to minimise the effects of loss of offsite power on the operation of the nuclear power plant.

2.5.2.3 SOER 2001-1: Unplanned Radiation Exposures

Analysis of events indicates there exists a continuing vulnerability to unplanned exposures at WANO member NPPs, both from the hazards associated with plant systems and from the risks associated with radiography work at our NPPs. Some of these unplanned exposures have exceeded regulatory exposure limits, and a few events have had potential for injury. As precursor events continue to occur, the potential exists for significant exposure events. Consequences of these events significantly affect the radiation worker, the associated plant, and more broadly, the whole nuclear industry.

2.5.2.4 SOER 2002-1: Severe Weather

Severe weather, including high winds, heavy rain and lightning, has affected many nuclear power plants around the world. The severity of the weather conditions has in some cases been greater than that considered in the design of the power plant. It is important therefore to learn from experience with severe weather to minimise challenges to nuclear safety.

Severe weather can affect a nuclear power station both internally and externally. Internally, wind and heavy rain can damage buildings and safety related equipment and make movement of staff around the site very difficult.
Externally the weather hazards can disrupt grid supplies and communication systems, and limit the ability for support staff and essential consumables to be brought to the site. Both these internal and external effects can challenge nuclear safety.

2.5.2.5 SOER 2002-2: Emergency Power Reliability

This SOER deals with the reliability of emergency power in nuclear power plants. Indeed, in SOER 1999-1 (Loss of grid), the risks and effects of loss of offsite power are clarified. One of the most important countermeasures is to have a reliable emergency power system (e.g. diesel generators). This emergency power is used for operation of several emergency systems for safe shutdown of the nuclear power plant and thus ensures the cooling of the reactor fuel. It has been noticed among WANO members that this emergency power reliability was degrading and needed focus from all nuclear power operators.

Probabilistic safety assessments at nuclear power plants world-wide consistently demonstrate that failure of emergency electrical power systems, leading to station black-out conditions and subsequent inability to cool reactor fuel, is one of the most credible scenarios that can lead to a core damaging event.

2.5.2.6 SOER 2003-1: Power Transformer Reliability

The rate of transformer failure is increasing as they reach the end of their normal life of 20-30 years. Many plants are not monitoring the factors that influence the ageing of transformers and therefore are at increased risk of faults. In addition, others do not have contingency plans to minimise the impact if a fault were to occur.

Events discussed in this SOER describe the severe impact that transformer failure can have on a station. It also discusses some of the major factors that influence the electrical ageing of power transformer and how to manage the risk of future failures.

2.5.2.7 SOER 2003-2: Reactor Pressure Vessel Head Degradation at Davis-Besse Nuclear Power Station - Rev1

On 6 March 2002, a cavity was discovered in the reactor pressure vessel (RPV) head adjacent to control rod drive mechanism (CRDM) nozzle 3 at Davis-Besse Nuclear Power Station. The technical aspects of boric acid corrosion degradation are discussed in WANO SER 2002-3, this Significant Operating Experience Report (SOER) discussed the organizational contributors.
that resulted in this avoidable event. A major contributor to this event was a shift in the focus at all levels of the organisation from implementing high standards to justifying minimum standards. The CRDM nozzle leak and the wastage in the Davis-Besse RPV head went undetected for several years, although symptoms of leakage and corrosion were present. Organizational weaknesses did not cause the CRDM nozzle leak, but they did affect the station’s ability to identify, evaluate, and correct the leakage before the RPV head was seriously damaged.

2.5.2.8 SOER 2004-1: Managing Core Design Changes

This SOER deals with events that happened mostly in light water reactors in the USA. As there was an economic drive to have longer fuel cycles (a typical fuel cycle was initially 12 months) towards 15 of 18 months, which implies the use of higher energy cores, the operators observed more fuel problems.

2.5.2.9 SOER 2007-1: Reactivity Management

This SOER deals with the events that happened between 2004 and 2007 regarding reactivity incidents. It was observed amongst the operators that most of the time when reactivity changes occurred, the operators relied on the reactor protection systems, instead of taking conservative and pro-active actions. The consequences of improper core reactivity management can be found in WANO Report \textit{In-reactor Fuel-damaging Events - A Chronology 1945–2003}. These problems and precursors are an indication of lacunes in nuclear safety culture.

2.5.2.10 SOER 2007-2: Intake Cooling Water Blockage

Between 2004 and 2007 44 events happened regarding intake cooling water blockage. These events have increased in frequency and happen in every type of nuclear power plant. The importance of the intake cooling water is considered a non-safety related area, and thus may not get the same focus and attention as is expected for safety related areas and equipments. Yet, 20% of the events analysed had an indirect impact on safety-related systems. The other 80% of the events had an impact on power generation, sometimes even leading to plant shutdown to fix the problem.
2.5.2.11 SOER 2008-1: Rigging, Lifting and Material Handling

An analysis of the events since 2002, show that there is an increase in risk while manipulating loads. These loads are manipulated in some of the events in the reactor building during refuelling operations, or in the vicinity of safety related equipment. The fall of these loads on safety related equipments is a very high risk.

Station standards for rigging, lifting and material handling should define the level of administrative control, training and supervisory oversight which is appropriate to the risk involved in performing these activities in relation to nuclear and industrial safety.
2.6 ORGANISATION OF ELECTRABEL

In this section the Electrabel organization with regard to nuclear power generation is explained.

Figure 7 - Organisational Chart of Nuclear operations at Electrabel

The nuclear power generation organization within Electrabel is under the hierarchy of a chief Nuclear Officer, who answers to the director of Power generation BeLux.

Under the chief nuclear officer there are the two site directors of Doel and Tihange, the asset management and safety division, whose mission is the plant life extension program and the decennial safety review of the nuclear power plants and the Nuclear fuel, PPM (Process Performance Management) and liabilities division, whose mission is the management and purchase of nuclear fuel, the optimization of process performance management and takes into account the liabilities (risk management).

The two organizations of Doel and Tihange are similar, the organizational chart of Doel is shown hereunder:
Figure 8 - Organisational chart of NPP Doel

Each department has a proper mission which is mentioned hereunder:

- **Operations**: Safe operation of the nuclear power plant according to the technical specifications. They are responsible for the availability of the plant as a whole.

- **Maintenance**: Maintenance and asset management of the installations. They are responsible for the availability of the equipments.

- **Care**: This department is responsible for radio protection, industrial safety, nuclear safety, environment, fire protection and site security.

- **Engineering**: Is responsible for realisation of large renovation projects and for the role of design authority as defined by INSAG 19 (see appendix 6).

- **External Communications**: is responsible for all press communication.

- **Human Resources**: Supports the organisation with personnel related issues.
3 METHODOLOGY TO ANALYSE A SOER

In this chapter an explanation will be given how a SOER is made up. We will explain what kind of analysis the WANO expects from its members regarding a SOER. Furthermore the SOER’s that have been analyzed in the past by Doel will be challenged with regards to the expectations of WANO. This is necessary so a conclusion can be made which analysis method is the most efficient and effective.

3.1 SOER: BUILD – UP

3.1.1 Purpose of a SOER

A SOER is published by WANO when the WANO organization, by doing analyses of the events occurring in all her member nuclear power plants, finds there are too many events happening in a certain domain, and thus needs more attention by its members. The SOER explores the direct and indirect causes for a series of events, and provides an analysis of the failed barriers and process weaknesses that contributes to these events.

When a SOER is published, WANO members are expected to closely review this SOER with regard to the procedures, policies and practices in the members’ nuclear power plant in order to determine how this operating experience can be applied at the member nuclear power plant to improve safety.

Implementation of the recommendations contained in a SOER is evaluated during WANO Peer reviews beginning one year after publishing of the SOER.

3.1.2 Content of a SOER

The SOER normally consists of several documents which are:

- Main document :
  - SOER report
- Supporting Documents :
  - SOER summary
  - How to review WANO SOER …
  - Training supplement
First of all, the SOER’s have a specific nomenclature. Each SOER has a year, which corresponds to the year the SOER was first published, and is followed by a serial number and a title.

The content of the different documents will be presented hereunder:

- **SOER report**: the WANO SOER report begins with its reason of existence, and with the deadline by which the nuclear power plants have to answer to the recommendations in function of the next planned WANO peer review which evaluates the nuclear power plants response to the SOER. It continues with a summary of the SOER and with the results from analyzing the different events that happened in different nuclear power plants. The results from the analysis are illustrated with the actual events that happened at the different nuclear power plants. If applicable, the WANO guidelines, which are good practices for a certain domain, are mentioned, because the guidelines could have the answer to countering the event from happening.

  The different causes are regrouped in categories. For each category, the SOER report formulates recommendations, which are formulated in a direct, formal way, e.g. “All core reactivity changes and mode changes must be directed by detailed operating procedures or approved reactivity plans to prevent errors and misunderstandings. Management specifies when procedures need to be ‘in hand’ for reactivity manipulations.” (SOER 2007-1, Recommendation 1 : Standards and expectations).

  At the end, the report contains a reference list, which contains the event descriptions on which base the SOER was established.

- **SOER summary**: as the title of the document indicates, this document is a summary, usually between two to four pages long. The summary enumerates the different events that happened at multiple nuclear power plants, and thus justifies the reason of existence of the SOER. It formulates the conclusions from the SOER that WANO has established, based upon the root cause analysis and barrier analysis done by WANO on all these events. The summary is concluded by enumerating the WANO recommendations that each WANO member has to address. Each recommendation can consist of multiple sub recommendations.

- **How to review SOER …:** this document is a guide for WANO Peer Review teams as a tool to guide the team’s evaluation of the effectiveness of SOER recommendation implementation. This document can also be used as a self-assessment tool to make sure that all aspects of each SOER recommendation have been considered, and that
the actions proposed are appropriate to address the issue. The different recommendations are grouped together in areas (operations, maintenance, training…) which are not necessarily one to one relations with existing organizations at nuclear power plants.

- Training supplement: this document consists of two parts, namely a PowerPoint presentation and a teacher’s aid. The purpose of SOER’s is not only that they are analyzed at nuclear power plants by a limited number of persons but also that the necessary training is given to the operating personnel. Thus awareness of the risks and possible effects can be increased among nuclear power plant operating personnel.
3.2 WANO EXPECTATIONS

In this part an explanation will be given regarding the way WANO expects the SOER to be analyzed by nuclear power plants.

As mentioned before, the WANO writes in its SOER a number of recommendations which have to be addressed by nuclear power plants in their analysis. These recommendations are regrouped in domains.

If we take the recommendations from SOER 2007-2: intake cooling water blockage, the domains are:

- Changing environmental conditions
- Monitoring techniques
- Design and modification
- Material condition and maintenance program
- Operational procedures and training

If we look closer at the first recommendation, the following sub recommendations are mentioned:

- Identify and analyse all plausible initiating conditions (debris…)
- Capture and trend…
- Review environmental laws…

Each of the sub recommendations can be attributed to different specialists, which have to answer how they comply with this recommendation. This must be proven by existing procedures, training or available equipment.

Each recommendation should receive an evaluation by the nuclear power plant member and should have actions if a gap with regard to the recommendation exists.

3.3 REVIEW OF SOER’S ANALYZED BY DOEL

Several SOER’s have already been analyzed in the past with different methods. In this paragraph these analyses will be reviewed. This means that the original SOER with the recommendations will be verified with regard to the gap analysis and the defined actions, which are already implemented, of the original SOER, thus to see if there still exists gaps.

If there are still gaps, this means that the original analysis method was not effective enough.
The SOER’s that have been treated in the past showed different levels of quality depending on the methodology used to analyse the SOER. Older SOER’s were not written in a direct, concrete way and let the possibility open to interpret the recommendations. This evolved over the years as WANO gained more experience in writing SOER’s and based on the experience feedback from its members.

3.3.1 Evaluation of analysis SOER 1998-1 – Safety system status control

This SOER, on safety system status control, was analyzed by two different persons with an operations background, respectively from unit Doel 1-2 and from unit Doel 3 – 4.

The recommendations from the SOER which had to be addressed were the following:

- **Recommendation 1a (Operations)**: Verify that clear procedure guidance has been developed and implemented for safety system restoration and recommissioning following outage periods
- **Recommendation 1b (Maintenance)**: Verify that clear procedure guidance has been developed and implemented for post-maintenance testing of safety systems to ensure that these systems are operable and meet design requirements following maintenance activities
- **Recommendation 1c (Engineering)**: Verify that clear procedure guidance has been developed and implemented for post-maintenance testing of safety systems to ensure that these systems are operable and meet design requirements following maintenance activities – Concerning guidance for post-maintenance testing of safety systems, consider both component functionality and overall system design and operability testing requirements. For example, this guidance should require post-maintenance operability testing of safety systems whenever motive power and/or control functions have been disabled to support system maintenance
- **Recommendation 1d (Maintenance)**: Verify that clear procedure guidance has been developed and implemented for the review of outage schedules, particularly changes to these schedules to identify activities that may affect safety system operability
- **Recommendation 2a (Operations)**: Establish and communicate to plant workers clear management policy and guidance that address the potentially unfavorable effects of outage schedule pressure on shift crews
- **Recommendation 2b (Operations)**: Establish and communicate to plant workers clear management policy and guidance that address the use of and adherence to
procedures and administrative processes that control outage testing and post-outage safety system restoration to operable status

- Recommendation 3 (Training) : Provide initial and continuing training for appropriate plant personnel on safety system status control. This training should ensure appropriate workers understand and can implement procedure requirements described in recommendation 1. Additionally, this training should address and reinforce plant management's expectations for managing schedule pressure and for procedure and administrative process adherence described in recommendation 2

The analysis performed in 1999 defined several gaps and gave rise to 15 actions to close the gap and be compliant with the recommendations formulated in the SOER.

By doing a review of the SOER with regard to the present organisation and work methods, following gaps are found with regard to two recommendations, namely recommendation 1b and recommendation 2b :

- Weaknesses in requalification process
  - The knowledge and expectations with regard to the requalification process are not known enough within the Operations and Maintenance department
  - Performed requalifications must be validated and consultable
  - There is a final barrier present with regard to planned activities, but not for urgent activities or supplementary activities during an outage
  - Some incidents have occurred which could have been avoided if the requalification process would have been followed more strictly

- Weaknesses in adherence to procedures :
  - The expectations with regard to the use of procedures
  - The expectations with regard to prejob briefing
  - The expectations with regard to manipulation of locked valves
  - The expectations with regard to changes in alignment of circuits
  - Stimulating a questioning attitude

Several additional actions were identified to improve the application of this SOER.

Based upon this evaluation of the original analysis, I found that several gaps still existed because not all of the aspects were covered in depth by the original analyzers. This was due to the lack of knowledge of the process over the site.

An analysis of the SOER at the time by a person responsible for the requalification process over the site, would have countered these gaps.
3.3.2 Evaluation of analysis of SOER 1999-1 with addendum – Loss of grid

This analysis was done by the Engineering department, more specifically the electrical department within Engineering. Several actions were defined in 1999 – 2000. This SOER has been reevaluated in 2006 due to the 2004 addendum that was published, and because of the recent event in Forsmark which had an impact on the European electricity grid.

The reevaluation was done by the division head of electrical Maintenance in close cooperation with the test engineer of unit Doel 3-4.

The SOER 1999-1 had the following recommendations:

- **Recommendation 1A**: Establish appropriate interfaces between nuclear power plants and grid operators such that: Planning for plant safety system maintenance and testing activities that could affect electrical supply diversity is coordinated with the grid maintenance and testing activities to prevent inadvertent reduction in nuclear plant defence-in-depth.
- **Recommendation 1B**: Establish appropriate interfaces between nuclear power plants and grid operators such that: Plant operators are provided early warning from the grid operator of potential or developing grid instabilities.
- **Recommendation 1C**: Establish appropriate interfaces between nuclear power plants and grid operators such that: Grid operators are apprised of the unique plant operating restrictions and requirements associated with operation of nuclear power plants with respect to nuclear safety.
- **Recommendation 1D**: Establish appropriate interfaces between nuclear power plants and grid operators such that: The nuclear unit is clearly recognised as an important load (customer) from a nuclear safety perspective. This relationship should be reflected in grid operator load-shedding schemes.
- **Recommendation 1E**: Establish appropriate interfaces between nuclear power plant and grid operators such that: The responsibility (ownership) for grid equipment maintenance is clearly defined between the plant and the grid operator.
- **Recommendation 1F**: Establish appropriate interfaces between nuclear power plants and grid operators such that:
  - Binding agreements exist between the plant and the associated grid operators to identify and communicate their responsibilities. These agreements should identify off-site power requirements and the importance of meeting these
requirements and recognise that nuclear plants have high priority when restoring power. In addition, these agreements should specify the following:

- Protocols (communication and coordination) for restoration of off-site power to the nuclear plant on a priority basis
- Switchyard maintenance and design change implementation practices necessary to ensure reliable off-site power
- Review of design changes to the plant switchyard(s) prior to implementation
- Timely notification to the nuclear plant when grid stability analysis changes indicate the potential for more severe switchyard or plant equipment service conditions during grid transients

- Recommendation 1G Establish appropriate interfaces between nuclear power plants and grid operators such that: Establish specific points of accountability to provide effective monitoring and oversight over all grid, switchyard and plant activities that potentially affect off-site power.

- Recommendation 2A Review adequacy of procedures for loss or degradation of the electrical grid to ensure that:
  - Actions to be taken in the event of grid instability and voltage degradation are specified, including criteria for pre-emptively placing safety systems on emergency power supplies and for conservatively placing the plant in a safe operating or shutdown condition when significant threats to grid stability exist.
  - Procedures clearly describe contingency actions when operators determine or are notified by the grid operator that predicted off-site voltage levels during post-trip conditions are insufficient.

- Recommendation 2B : Review adequacy of procedures for loss or degradation of the electrical grid to ensure that: Clear guidance exists for manual configuration of electrical buses when automatic bus transfers fail to actuate or when manual alignment of emergency power is necessary.

- Recommendation 2C : Review adequacy of procedures for loss or degradation of the electrical grid to ensure that: Operating procedure guidance reflects the importance of timely resetting (rearming) of safety system electrical sequencing equipment following the return to grid power

- Recommendation 2D : Review adequacy of procedures for loss or degradation of the electrical grid to ensure that: Management expectations clearly communicate that, following a loss of grid that involves a plant transient or trip, the operating crew's
immediate focus should be on stabilising the plant in a safe condition rather than on rapidly returning the plant to power operation

- Recommendation 3A: Verify that plant and switchyard high-voltage grid distribution equipment for which the plant is responsible is fully incorporated into the plant preventive maintenance programme. Review and provide oversight of preventive maintenance programmes for plant switchyard equipment owned by the plant and other organisations to ensure these programmes support reliable off-site power to the plant.

- Recommendation 3B: Verify that plant and switchyard high-voltage grid distribution equipment for which the plant is responsible is fully incorporated into the plant preventive maintenance programme. Ensure that main generator voltage regulators, governor controls and load tap changers are in the plant preventive maintenance programme and that the equipment configuration and associated setpoints are maintained consistent with grid operator analyses.

- Recommendation 4: Review trip setpoints for safety-related components to determine if degraded grid voltage may result in unanticipated component trips prior to emergency power source automatic actuation. Identify and implement corrective measures for vulnerabilities discovered by this review. Periodically review, confirm and update the grid reliability and stability design assumptions to ensure they remain valid following changes or modifications to the plant and to the grid. The review should include the following, as a minimum:
  - Grid restoration time assumptions to restore off-site power sources to the plant
  - The impact on plant voltage limits and voltage predictions following a generator trip, including whether a generator trip could result in a loss of off-site power

- Recommendation 5A: Incorporate degraded grid voltage conditions into operator training (in addition to complete loss-of-grid training). Provide operator training on post-loss-of-grid recovery actions, including additional grid losses during recovery phases and on manual electrical bus alignments that may be necessary during complicated loss-of-grid events. Conduct drills or simulations to verify adequacy of loss-of-grid procedures and training. In addition, incorporate the following into initial and continuing operator training: Describe the relationship between pre-trip grid voltage and post-trip grid voltage requirements and the grid’s capability to maintain off-site power sources operable or capable to support station equipment safety functions

- Recommendation 5B: Incorporate degraded grid voltage conditions into operator training (in addition to complete loss-of-grid training). Provide operator training on post-
loss-of-grid recovery actions, including additional grid losses during recovery phases and on manual electrical bus alignments that may be necessary during complicated loss-of-grid events. Conduct drills or simulations to verify adequacy of loss-of-grid procedures and training. In addition, incorporate the following into initial and continuing operator training: Provide training on basic grid concepts, including voltage control requirements and how controlling voltage relates to operability of the off-site power sources.

- Recommendation 5C: Incorporate degraded grid voltage conditions into operator training (in addition to complete loss-of-grid training). Provide operator training on post-loss-of-grid recovery actions, including additional grid losses during recovery phases and on manual electrical bus alignments that may be necessary during complicated loss-of-grid events. Conduct drills or simulations to verify adequacy of loss-of-grid procedures and training. In addition, incorporate the following into initial and continuing operator training: Determine the ability of the simulator to replicate the plant’s nonsafety-related load response under degraded voltage conditions. If the simulator modelling is complete and accurate in this regard, conduct dynamic simulator training sessions on the plant’s response to degraded voltage conditions. Otherwise, discuss the expected response as part of licensed and nonlicensed operator initial and continuing training.

- Recommendation 5D: Incorporate degraded grid voltage conditions into operator training (in addition to complete loss-of-grid training). Provide operator training on post-loss-of-grid recovery actions, including additional grid losses during recovery phases and on manual electrical bus alignments that may be necessary during complicated loss-of-grid events. Conduct drills or simulations to verify adequacy of loss-of-grid procedures and training. In addition, incorporate the following into initial and continuing operator training: Incorporate aspects identified in recommendation 7 during periodic emergency plan drills or simulations.

- Recommendation 6: Review the plant’s compliance with criteria from national and regional grid authorities and identify areas where plant improvements can assist the grid’s response to disturbances without sacrificing plant safety. Implement changes that are appropriate, and share design vulnerabilities with the industry through the operating experience program. For example, plant improvements could include setpoint changes and equipment protection trips.

- Recommendation 7: Review the plant’s ability to respond to loss-of-off-site-power conditions to identify potential complications when nonessential power is lost for an
extended period of time. Implement changes that are appropriate. The review should include the following, as a minimum:

- The plant’s ability to maintain effective communications, both internally and externally, when normal and/or off-site power sources are lost and the station is being powered from emergency power sources—This includes the capability to contact off-duty plant personnel and outside organisations under regional blackout conditions when mobile (cellular) telephone and pager systems may be stressed.
- The plant’s emergency response processes, including off-site notification capabilities and plant personnel contact information
- The plant’s ability to access important or critical plant information (e.g., design drawings, calculations, and tagging programs) normally contained in electronic files that would be needed during a loss of power

- Recommendation 8: Identify and report equipment problems and vulnerabilities associated with plant switchyards through the operating experience programme, to enable nuclear plants to better understand the problems occurring with switchyard equipment

Based on the re-evaluation, several actions were added to be compliant with the last version of the SOER:

- A repeated information towards the grid operator ELIA of the importance of the external high voltage grid for the nuclear power plants
- Maintenance on the high voltage equipment will be reevaluated based on the RCM (Reliability Centered Maintenance) principle
- Change the operational procedures EXPL/O/07 of Doel so that it is clear that stabilising the unit is the highest priority after a SCRAM, returning to electricity production is of less importance
- Establishing a contingency plan for a long lasting black out.

These supplementary actions were not defined in the original analysis, partly because of the different organisation of Electrabel (Elia was a member of Electrabel as CPTE), and thus the first additional action was not necessary at that time. The other actions were added with the addendum and with the Forsmark incident. These actions were not necessary for the original SOER.
The weakness of the analysis method as applied for this SOER is that there was no periodic review of the SOER when the environment / organisation changed. Therefore it is useful to have a periodic review of the SOER’s on a frequency basis of 2 to 3 years, thus to be sure that all the recommendations are still met.

3.3.3 Evaluation of analysis SOER 2001-1 – Unplanned radiation exposures

The initial analysis was performed by the head of the radio protection division. The person in this function has all the knowledge and skills to analyze this SOER. Additionally this division works on all four units, so this means that the methods and procedures for this division are equal for all the units, and thus this makes the analysis of this SOER and the definition of the actions to close the gap more easy.

The recommendations mentioned in the SOER 2001 – 1 are the following:

- Recommendation 1 (RP) : Clearly communicate the senior utility management recognition of radiation safety as an important responsibility of our industry, and communicate commitment to the importance of radiation safety to all nuclear power plant workers. Emphasise the importance of a high level of awareness and sense of individual responsibility with regard to personnel radiation protection with specific attention to complying with rules and following existing administrative procedures and processes.

- Recommendation 2 (RP) : Fully integrate the radiation protection management team into NPP operations and the NPP line management organization. Examples include integration of the radiation protection team in work planning activities, outage planning and scheduling activities, plant modification reviews, and plant strategic decision-making processes.

- Recommendation 3 (RP) : For those jobs where large doses could be received in a short period of time, require direct involvement by both radiation protection staff and work supervisors in ALARA reviews, planning, preparation, and performing of the job. Radiation protection staff and work supervisors should ensure that necessary surveys and other radiation protection measures required by ALARA planning are implemented at the work site, and include pre-job briefings, review of prior operating experience related to the work, and adequate radiation exposure reduction reviews.

- Recommendation 4 (RP) : The training and retraining programs should stress the potential for abnormally high or rapidly changing radiological conditions, including the
actions required when these conditions occur. Training should also emphasize the importance of a high level of awareness and sense of individual responsibility with regard to personnel radiation protection

- **Recommendation 5 (RP)**: Radiation protection training and retraining for plant personnel should include a review of selected industry events involving large, unplanned exposures and the responsibility of individuals for the prevention of such events. Additionally, for personnel who perform dose rate surveys and monitoring, this training should address the proper operation of dose rate monitoring equipment

- **Recommendation 6**: Ensure that activities with the potential for high radiation exposure (for example, exposure rates greater than 1.5 rem/hour or exposure greater than 500 mrem per entry) are controlled by written procedures and/or specific radiation work permits.

- **Recommendation 6a (RP)**: Procedures or radiation work permits should contain specific radiation protection instructions to prevent unplanned exposures

- **Recommendation 6b (RP)**: Procedures or radiation work permits for these activities or areas should contain (in addition to the normal requirements for the existing radiation dose rates) requirements for the use of maximum allowed time in the area, pre-determined cumulative doses allowed for the job, and for continuous radiation protection coverage, either physically or through remote monitoring methods.

- **Recommendation 6c (RP)**: Procedures or radiation work permits should contain specific instructions concerning the frequency and type of radiation surveys and at what dose rates, or accumulated dose to an individual worker, the area is to be evacuated

- **Recommendation 6d (RP)**: A caution or radiological hold point should appear immediately prior to those steps in procedures or radiation work permits that could, when carried out, cause a significant increase in work area dose rates (for example, greater than 10 millisievert per hour).

- **Recommendation 6e (RP)**: Where available, electronic dosimeter, with alarms for dose rate and cumulative dose appropriately set for the task, should be required by procedures or radiation work permits. Those NPPs that currently do not use electronic dosimeters should seriously consider the purchase and use of such devices.

- **Recommendation 6f (RP)**: Entry into very high radiation areas (for example above 1 Sievert per hour dose rate) should have the written approval of the radiation protection manager
• Recommendation 7 (RP): Perform effective periodic reviews of radiation protection deficiencies, including those involving human performance errors, to identify the root causes and precursors to unplanned exposures. Adverse trends should be reported to plant management for appropriate corrective action. These reviews should ensure that work control systems including radiation work permits, procedures, and work orders adequately address radiological controls, including the potential for changing radiological conditions. Additionally, periodic self-assessments of radiation protection department performance should be performed to identify and correct radiation protection program and process weaknesses.

• Recommendation 8 (RP): Review plant areas to ensure that all areas with existing or potential high radiation exposure rates are identified and such areas are properly posted and controlled. This should include those areas that have the potential for changing radiation conditions.

The evaluation of the original analysis shows that no additional actions are necessary to be compliant with the recommendations mentioned in the SOER. The originally defined actions and work methods are sufficient.

As a parenthesis can be mentioned that the Doel power plant is internationally recognized as being one of the top performers with regard to radioprotection. This can be seen in the performance indicators of WANO which compares all the nuclear power plants over the world in different domains. In the underlying graph the result of the 4 units of Doel (bargraphs from left to right respectively) are compared to the rest of the world (best quartile of the world). Included is the average value for the site of Doel.

As one can see the result from Doel 3 is significantly higher than that of the other three plants, this is due to a Silver Ag$^{110m}$ contamination present in the primary circuit due to fault in the control rods and due to the presence of Co-58 and Co-60, which leads to a higher background radiation dose compared to the other three units. To lower the dose due to the Cobalt present, a modification will be implemented in the Doel 3 Power plant, using an injection of Zn which will replace, in a very thin oxide layer, the Co-58 and Co-60 deposits in the RC circuits.
3.3.4 Evaluation of analysis of SOER 2002 – 1 – Severe weather

This SOER was analysed by different persons from different departments in 2002 – 2003. As a result a number of actions were defined, but it is unclear which actions correspond to which recommendations. By evaluating the original analyses, the defined actions were linked to the recommendations of the SOER, and it was found that gaps still existed, which lead to the definition of additional actions.

The recommendations of the SOER are:

- Recommendation 1 (Engineering) : Review the design safety analyses for severe weather hazards at the plant to ensure that all credible severe weather conditions are adequately addressed. This should include a review of the design criteria limits for severe weather to ensure that all credible severe weather conditions are included in the design safety analysis. Specific aspects of this review should include:
- The potential challenges (e.g. flooding, heavy rain or snow, wind damage/windblown debris) to safety related equipment operability.
- The adequacy of consumable stock levels required on site and the ability to resupply consumable stocks during and following severe weather conditions.
- The adequacy of instrumentation and lighting to support any necessary operator actions during severe weather.
- The capability of exposed equipment such as switchgear, to withstand ice, lightning and high wind conditions.
- For coastal plants, the potential for grid instability or loss due to wind-blown salt deposits on electrical insulators.

- **Recommendation 2 (Organizational Effectiveness)**: Ensure that emergency planning arrangements are in place at the plant that specify the organizational, support staff and communication arrangements required to be available during severe weather. Also ensure that adequate training is carried out on these arrangements.

- **Recommendation 3 (Operations)**: Ensure the capability is available at the plant to provide prediction of severe weather conditions. These predictions should give information about the probability and potential severity of weather conditions at the plant.

- **Recommendation 4 (Operations)**: Ensure plant operating procedures are available to support the various actions to be taken on site depending on the probability and severity of the weather conditions predicted. These should include:
  - Actions, relevant to the type of severe weather predicted at the plant, to minimize potential wind-blown debris and to ensure that barriers, drainage and pumping systems to prevent flooding are available.
  - Actions to maximize safety and standby equipment availability.
  - Verification of safety related equipment and communications system operability, consumable stock levels, and staffing arrangements for the period of the predicted severe weather.

- **Recommendation 5 (Organizational Effectiveness)**: Ensure an effective decision making process is in place at the plant for actions to be taken during severe weather, including:
  - The authority and responsibility of the operations shift staff and other essential staff involved should be clear and supported by relevant procedures and guidelines.
o The decision making process should address specific issues such as when the units should be shut down, reduced in power or placed in a safe state, actions during islanded conditions (area local to the plant isolated from main grid network) and when to reconnect the site to grid supplies following grid instability.

When the analyses are reviewed, the following is found:

- The Maintenance department did no analysis, they decided the SOER was not applicable for them, since maintenance only foresees the tools and equipment if needed
- The Operations department referred to an analysis of another event that happened in a power station in France, and to the decennial SAR (Safety Assessment Review)
- The Fuel department did no analysis, actions would be taken if needed following the analysis done by the operations department
- The Engineering department did no analysis with the mention that is was not applicable to engineering
- The Care department made an analysis with regard to flooding of the site, the other extreme conditions with impact on the safety equipment are not considered

As a conclusion, one can say that for this SOER no proper response / analysis was done

Due to the lack of analysis and actions, the WANO has issued a warning during the last WANO Peer Review in 2006 towards Doel with regard to this SOER of not being analyzed in a formal way. The analysis was redirected towards a subject in the ten yearly safety assessment.

At present the SOER is reanalysed in a formal way and proper actions are defined.

For this SOER one can conclude that splitting up the analysis is not a good thing to do, as no one takes ownership of the problem. Since there was no follow – up by the management, there was no commitment from the researchers to combine the results into a single report.

3.3.5 Evaluation of analysis of SOER 2002 – 2 – Emergency power reliability

The analysis on this SOER was done by one person of the Maintenance department, who is responsible for the maintenance on the diesel generators, which are the emergency power source for the Doel nuclear power plant.
The recommendations of the SOER are:

- **Recommendation 1:** Review existing emergency power system design for vulnerabilities to common cause and common mode failure. Verify the validity of existing analysis or conduct additional analysis as needed to assure that potential common cause and common mode failures are identified and addressed. Implement appropriate changes to system design as found necessary by this review.

- **Recommendation 2:** Review existing emergency power system operating and maintenance practices for vulnerabilities to common cause and common mode failure. These reviews should encompass normal, abnormal, and emergency operating modes, system configurations during surveillance testing, and system conditions established to support maintenance. Implement appropriate changes to system operating and/or maintenance practices as found necessary by this review.

- **Recommendation 3:** Review modification processes used to implement changes to emergency power systems to ensure that rigorous modification controls are applied.

- **Recommendation 4:** The use of the term "emergency power system" in the following recommendation is intended to encompass emergency power generators, necessary auxiliary systems, associated emergency electrical distribution systems, and required control logic systems to the extent that these systems are defined by each nuclear power plant’s (NPP’s) licensing and/or design requirements.

- **Recommendation 5:** The use of the term "emergency power system" in the following recommendation is intended to encompass emergency power generators, necessary auxiliary systems, associated emergency electrical distribution systems, and required control logic systems to the extent that these systems are defined by each nuclear power plant’s (NPP’s) licensing and/or design requirements.

Review testing practices for emergency power systems to verify that the practices are representative of actual demand conditions and appropriately exercise equipment that is expected to respond in an actual demand condition. Staff performing this review should identify and use applicable industry best practices for comparison to current testing practices at their NPP. Implement appropriate changes to system testing practices as found necessary by this review.

- **Recommendation 6:** Review maintenance practices to verify that both contract and NPP personnel performing maintenance on emergency power systems are closely supervised by appropriate NPP supervisory staff, briefed on work package
requirements and allowed work scope, and understand requirements to clearly document work performed

While the analysis was complete and thorough, a review of the SOER by me showed that no additional actions were needed for the mechanical enhancements. There still needs to be a review of electrical gaps and eventually actions, as has been reported by the WANO Peer Review in 2009. This analysis will be done by the division head of electrical maintenance.

3.3.6 Evaluation of analysis of SOER 2003 – 1 – Power transformer reliability

The analysis done by WANO shows that the risk to have an incident on a power transformer is 1 out of 10. The analysis of the SOER was done by the maintenance equipment specialist of transformers.

Transformers are the main equipment of electric power input to the station distribution system and power output from the main generator. The scope of this SOER is to evaluate transformers that service normal station auxiliaries and load centers, such as feedwater pumps or circulating water pumps; emergency station auxiliaries and load centers, such as a backup to an emergency diesel power supply or power to an emergency core cooling water pump; and main generator step-up (GSU) transformers. Some switchyard transformers, including auto transformers, may be within the scope of the SOER if they are critical components to support safe and reliable plant operation (These transformers are oil-immersed and located outside in a switchyard with an oil containment basin.).

The transformers are normally considered functionally critical with a low duty cycle and mild service conditions.

Oil-filled transformers are typically rated from 5 MVA to greater than 100 MVA. Low voltage windings are rated at the station service voltage, typically 5 KV, and at the generator output voltage, typically 25 KV. High voltage windings are rated at the transmission distribution voltage, typically greater than 115 KV.

Transformers cores are classified as a core-form construction (Figure 10) or shell-form construction (Figure 11).
The core is built up with grain-oriented silicon steel plates. Windings and magnetic cores are assembled on a steel base structure. After vacuum immersing and drying process, the windings provide a reliable insulation and tight structure; so that sufficient strength can be secured against an external short-circuit.
A close-fitting tank fits over the core and coil assembly and is welded to the steel base. With compact construction and coolers, the temperature rise of the transformer is kept below the rated value when at full load. Higher transformer capacity is achieved by forced cooling using a combination of fans and oil pumps.

The transformer is cooled using oil coolers. A transformer oil leak is likely to require absorbent bags. Containment basins are usually installed and the stones around the transformer may have to be excavated and removed to avoid ground contamination and environmental penalties if an oil leak occurs.

Windings are connected to high (H) and low voltage (X) bushings and surge arrestors. Current transformers are installed on the winding for protection and metering. For GSU transformers, isophase bus supplies low side bushings have the highest bushing current ratings and may operate in the highest ambient temperature condition. Windings have hot spot temperature instrumentation. High voltage windings may have tap changers. Some stations recondition and repair bushings.

Transformer electrical tests include an insulation resistance test, insulation power factor tests, insulation capacitance test, and a transformer turns ratio test. Oil samples are drawn and analyzed for electrical insulation integrity and gas content. Transformers are electrically protected using calibrated protective relays in current and potential transformer circuits.

The recommendations of this SOER are:

- Recommendation 1: Establish and implement effective monitoring and trending of large transformers. A monitoring strategy is required to be able to predictably determine when the transformer needs to be inspected and possibly repaired to prevent event. Use diagnostic transformer test data to detect and analyze degraded conditions and plan follow-up transformer maintenance activities. Evaluate oil and dissolved gas test results, temperature trends, thermographic analysis, pump vibration trends, and instrument data to detect degrading conditions. Data from operator rounds should be tracked and trended. Develop a long-term plan for monitoring, testing, and trending the station’s large power transformers. Evaluate support and protection logic schemes, considering applicable industry operating experience. For single-point failure vulnerabilities, identify potential sources of spurious transformer trips that can be caused by an improper actuation of a single relay or component. Make appropriate changes based on the results of this evaluation.
Recommendation 2a: Develop and implement a predictive and preventive maintenance program based on transformer years of service, risk importance, duty cycle, and environmental conditions that considers the following:
  - Dissolved gas analysis
  - Oil analysis
  - Infrared thermography
  - Temperature monitoring trending
  - Electrical testing of transformers, bushings, arrestors, tap changers, and current transformers
  - Functional checks of alarm and trip circuits
  - Tap changer maintenance and functional testing
  - External cooler inspection for cleanliness and leaks
  - Bushing inspection and cleaning—Isophase bus bushings may have special considerations
  - Maintenance inspections/engineering walkdowns
  - Grounding resistor inspection
  - Protective relay calibration and replacement of electrolytic capacitors
  - Preventive maintenance on low voltage motors, power supplies, and automatic transfer switches
  - Vendor recommendations and industry guidelines for periodic inspection, maintenance, and refurbishment frequency

Recommendation 2b: Develop a contingency plan for internal inspections for use if indications of significant degraded conditions are detected. The plan should be based on applicable industry operating experience and include items such as inspections of transformer connections and processing of transformer oil, if required, because of degraded condition or dissolved gases.

Recommendation 2c: Verify adequate spare transformers and transformer parts inventory requirements have been identified and that a process exists for performing monitoring and preventive maintenance as needed on the spare components. Verify critical spare parts are ready for installation

Recommendation 2d: Develop a plan for transformer replacement that considers the following:
  - Safety clearance and grounding
  - Disassembly
  - Oil removal and reprocessing
o Removal and control of parts to be reused
o Heavy load movement and necessary equipment
o Facility support such as temporary power for oil processing and spill control/containment
o Vendor or corporate support mobilization
o Reassembly coordination
o Retest requirements and test equipment availability
o Energization plan and post-energization monitoring

• Recommendation 3 A: Conduct thorough operator or maintenance rounds on major station transformers and spare transformers. Parameters should be recorded and evaluated for acceptability, and may vary depending on seasonal conditions or whether the unit is on-line or off-line. During spare transformer rounds confirm their readiness to be put in service.
  o Check temperature indications for oil and windings
  o Check blanketing gas pressure
  o Check proper pump and fan operation
  o Check for clear air passages
  o Check oil levels for transformers, conservators, and bushings as applicable
  o Check for oil leakage, unusual noises or smells
  o Check local alarm status and relay flags
  o Check desiccant condition

• Recommendation 3 B: Verify operating and abnormal procedures for transformer activities are sufficiently detailed and include the following:
  o Appropriate response to alarm conditions and/or off-normal conditions
  o Identification and correction of frequent spurious alarms for transformer problems
  o Procedures for alerting the system dispatcher when the station operator determines that transformer alarms received may result in a change in unit output power
  o Appropriate compensatory monitoring practices when alarms are out of service or sealed in for other reasons
  o Normal operating procedures that have current precautions and limitations based on recent vendor- or engineering-supplied information

• Recommendation 4A: Clarify responsibilities associated with transformer operation, maintenance, and performance monitoring
• Recommendation 4B: Provide effective management oversight of large transformers.
• Recommendation 5: Verify that transformer-related tasks (including tasks to operate, monitor, maintain, refurbish, and inspect transformers, and oversee these activities by contractors or off-site organizations) are included in the appropriate discipline training programs. In addition, verify that the training provided covers the causes and contributors of the events described in this SOER. If necessary, revise initial training materials and provide the appropriate training. Verify that the continuing training topic selection process considers transformer-related topics, including recent operating experience and changes to transformer operating, monitoring, maintenance, and engineering practices, to maintain the knowledge and proficiency of station personnel. Provide training for the station fire brigade, non-licensed operators, and the control room operators on transformer fire response. This training should take into consideration the possible isolation of the unit from the grid, as well as isolation of the site from the grid.

The review of the analysis showed no additional actions were found to be necessary.

3.3.7 Evaluation of analysis of SOER 2003 – 2 – Reactor vessel head

The analysis was originally done by the installation manager responsible for large nuclear components like the reactor vessel and reactor vessel head and was recently reevaluated because a revision of the SOER was published, where more attention was given to the nuclear safety culture aspect.
What is nuclear safety culture? This is defined by the IAEA in INSAG – 4. WANO has analyzed the INSAG 4 publication into guideline 2006-02 where the definition and principles are explained.

Safety Culture is an organisation’s values and behaviours – modelled by its leaders and internalised by its members – that serve to make nuclear safety the overriding priority.

The following are the nuclear safety culture principles:

1. Everyone is personally responsible for nuclear safety.
2. Leaders demonstrate commitment to safety.
3. Trust permeates the organisation.
4. Decision-making reflects safety first.
5. Nuclear technology is recognized as special and unique.
6. A questioning attitude is cultivated.
7. Organisational learning is embraced.
8. Nuclear Safety undergoes constant examination.
The recommendations mentioned in the SOER are:

- **Recommendation 1:** Discuss the Davis-Besse case study outline provided with this SOER, or a similar case study, with all managers and supervisors in the nuclear organization. Continue this effort on a periodic basis and for new managers and supervisors. Include in the discussions the technical and nontechnical contributors to the event described in WANO Significant Event Report 2002-3 and this SOER.

- **Recommendation 2:** Conduct a self-assessment to determine to what degree your organization has a healthy respect for nuclear safety and that nuclear safety is not
compromised by production priorities. The self-assessment should emphasize the leadership skills and approaches necessary to achieve and maintain the proper focus on nuclear safety. Consider using WANO Guideline GL 2002-01, “Principles for Effective Operational Decision Making” or the WANO Peer Review “Performance Objectives and Criteria”, Safety Culture section, as the basis for this self-assessment. Carefully evaluate any problems identified in the self-assessment that could adversely affect nuclear safety. Incorporate similar assessments in the organization’s ongoing assessment programs.

- Recommendation 3: Identify and document abnormal plant conditions or indications at your station that cannot be readily explained. Pay particular attention to long-term unexplained conditions. The sources for this information might include the corrective action database as well as discussions with experienced plant personnel. Include unexplained abnormal plant conditions as part of the case study discussion of Recommendation 1.

![Figure 14 - Picture of Davis Besse vessel head penetration](image)

The review of the original analysis of the SOER showed that the actions were still valid and that there were no additional actions needed. The revision 1 of the SOER had more attention for the nuclear safety culture aspect and the additional actions defined were:
In the training course given on Doel regarding “Conservative decision making”, an explicit mentioning should be included regarding the incident at Davis Besse and regarding the risks of boric acid corrosion

A special training course must be made which comprises the incident at Davis Besse and the lessons learnt for Doel. This training course is part of the initial training course of new personnel at the Doel power station

These additional actions belong to the domain of Training and Qualification and to the domain of Operating Experience, and the purpose of these actions is to make sure that new personnel would know the risks and incidents that happened at other nuclear power stations.

3.3.8 Evaluation of analysis of SOER 2004 – 1 – Managing Core Design Changes

This analysis was performed by the Fuel department in close cooperation with the Tractebel Engineering Department.

This WANO SOER is based on INPO SOER 03-2 and presents the analysis of the experience in light water reactor designs as utilities moved toward longer fuel cycles and higher-energy cores. Continued efforts to obtain defect-free fuel performance have, in many cases, been unsuccessful. In fact, an increase in reactor core performance problems has occurred in recent years. Analyses of these events reveal that weaknesses continue in the following areas:

- **Fuel-related** changes are sometimes made that are beyond the existing experience base, without sufficient consideration of the potential risks associated with the changes.
- **Chemistry changes** are being implemented that result in unanticipated adverse core and fuel performance.
- **Vendor analyses** of core design sometimes contain errors.
- **Predictive capability limitations** are not identified or addressed.

Such problems are precursors to potential core damaging events, which could occur if this trend continues. WANO SOER 2004-1 is intended to promote improved evaluation of risks associated with changes involving reactor cores and increased involvement of utility executives in reviewing and minimising these risks.
The recommendations were the following:

- **Recommendation 1**: Provide training on this SOER to appropriate senior managers, and appropriate engineering, core design, operations, and chemistry employees.
- **Recommendation 2**: Assess the extent to which the applicable key aspects of WANO SOER 2004-1 are addressed and the previous WANO ETR ATL 96-005 recommendations are implemented, and take appropriate corrective actions based on the assessment.
- **Recommendation 2a**: Perform risk evaluations when making significant changes to the core operating regime or fuel design. The evaluation should address the potential for anomalous core behaviour and identify appropriate contingency plans and monitoring requirements. Review risk evaluation results and monitoring plans with a senior nuclear executive before proceeding with a significant change. In addition, WANO members should promptly notify the industry of adverse reactor core or fuel performance events.
- **Recommendation 2b**: Evaluate both the effects of chemistry changes on core performance and core design changes on coolant chemistry.
- **Recommendation 2c**: Enhance relationships with fuel vendors.
- **Recommendation 2d**: Address limitations in core performance prediction tools

Due to the analysis of the SOER by Tractebel, who does the core design and fuel calculations for both Doel and Tihange, a number of improvement actions were defined, which are at present mostly completed or are near completion.

By reviewing the actions and interviewing the responsible of the fuel department regarding the SOER, the conclusion is that no additional actions are necessary at present. A follow up of the pending actions is necessary to ensure that they are completed in time. This is done by the fuel department.

### 3.4 CONCLUSION

After doing a review of all the analyses done in the past on the SOER’s, we can see that the SOER’s have been analyzed on different manners, each with different strengths and weaknesses.

Based upon all these analyses, the following conclusions and recommendations can be formulated in order to come to a better analyzing method of the SOER’s.
• Each SOER must be given to one person who has the final responsibility for the timely and correct analysis of the SOER with all its recommendations. This responsibility and ownership includes the follow up of the actions defined upon completion.

• The support of the management of the power plant is important, in case the organisation does not give timely response to the questions of the analyzer

• The researcher should preferably, but not mandatory, be the expert in the domain of the SOER

• The researcher of the SOER shall be assisted by experts when necessary, in order to have the correct analysis

• A final review and approval of the analysis by the management is mandatory, this will ensure quality and timeliness of the analysis

• A periodic review of the SOER’s is a good practice. This will ensure that due to for instance organisational changes, the recommendations are challenged with regard to the changing environment. This will also ensure that no new gaps are created.

These recommendations will now be used to analyze the SOER 2007 – 1 Reactivity management in chapter 4.
4 ANALYSIS OF SOER 2007-1 : REACTIVITY MANAGEMENT

In this chapter the SOER 2007-1 regarding reactivity management will be analysed. First the SOER itself will be explained, together with the recommendations the WANO has suggested. These recommendations will be challenged with regard to the current organisation and methods in use at the NPP of Doel. A gap analysis will be made regarding this SOER and corrective measures (if necessary) will be defined to be compliant with the recommendations of the SOER.

4.1 SOER 2007-1 : REACTIVITY MANAGEMENT

For nuclear safety, it is very important to control all the factors that affect the power lever and the criticality of the reactor core. Yet the WANO has found that many events happened in this area between 2004 and 2007, these events showed that there was failure to implement good reactivity management practices, as it is written in the WANO GL 2005 – 03 : Guidelines for Effective Reactivity Management.

“Reactivity management relates to the operating philosophy and specific guidance applied to controlling conditions that affect reactivity. This includes all activities that ensure core reactivity and stored nuclear fuel (where the potential for criticality can occur) are monitored and controlled consistent with fuel design and operating limits. It is a key factor in ensuring integrity of barriers to fission product release.”

The main reason of these events turned out to be personnel performance at nuclear stations. In many of the analysed events, the operators at the nuclear power plants relied on the reactor protection system, without taking pro – active conservative actions by themselves. Yet the potential consequences of incorrect core reactivity management can be fuel damage or worse, reactor core damage. This can be found in the WANO report “In reactor fuel damaging events: chronology 1945 – 2003”.

The events that took place in the different nuclear power plants over the world will be mentioned hereunder, but for confidentiality reasons any mention towards the actual power plants will be omitted. To better understand the working principles of the different kind of reactors, in appendix 7 an overview of the different type of nuclear power reactors is given.
4.2 EVENTS THAT HAPPENED IN NUCLEAR POWER PLANTS

4.2.1 Events while power plants were at steady state power

4.2.1.1 Reactor core power change due to Xenon change with control rods in manual control mode

In an advanced gas reactor (AGR) an unplanned power increase of 60 MWth occurred on a reactor during control rod power supply testing and peaked at 1340 MWth, which is above the 1290 MWth limit. Routine control rod relay testing required the control rod power supplies to be switched off; inhibiting the movement of regulating control rods. The testing began immediately after nine fresh fuel assemblies were loaded into the core and reactor power was increased to a ‘parking’ load of approximately 1280 MWth. As a result, reactor power increased because of positive reactivity in the core from xenon burnout. The reactor almost tripped on high flux protection with three low margin-to-trip alarms sealed-in. In response to the unexpected power increase, an operator throttled the inlet guide vanes (IGV) to reduce gas mass flow—to reduce core reactivity.

In an AGR, when all systems are in automatic control, closing the IGVs increases core outlet temperature and normally control rods insert, thereby reducing reactor power. During this event, with control rods in manual, throttling the IGVs further complicated plant response when the control rods were returned to their normal power supply. When the control system was placed back in its auto/normal position, the reduced IGV setting resulted in control rod insertion and an unintended power reduction of 180 MWth.

Operators exhibited two specific fundamental knowledge weaknesses. First, operator knowledge of reactor physics and how changes in neutron flux impact the production and burnout of xenon in the core. Operators knowingly deenergised control rod power supplies when core xenon was not at equilibrium conditions and was burning out faster than being produced because of the increased neutron flux. The xenon burnout added positive core reactivity and increased reactor power. Secondly, operators did not understand the interaction between the reactivity control systems and the impact on core reactivity. An operator throttled the IGVs to stop the reactor power increase, but there was no effect because the control rods were not energised.
Subsequent energisation of the control rods caused the control rods to drive into the core and lower reactor power by 180 MWth. The operator did not realise that reducing the IGV position had no effect on core reactivity because the auto-normal control was not selected.

The work planning process contributed to the overpower condition by allowing the control rod power supply tests to be scheduled during refuelling activities. A risk assessment was not considered in preparation for power supply testing. Additionally, there were no compensatory actions when the control rod power supplies were de-energised to counteract any core reactivity changes from xenon. Operating procedures did not prevent control rod power supplies from being de-energised during or after refuelling activities or warn operators to be aware that xenon concentration changes directly affect reactor power. The reactor operator also bypassed a procedure step to energise one control rod power supply when the test is completed on the first power cabinet.

In addition to the plant events analysed, WANO peer reviews have highlighted similar reactivity-related problems and precursors. These problems are also an indication of potential shortfalls in nuclear safety culture, particularly in recognising that nuclear technology is special and unique. In light of these reactivity events, utility managers are encouraged to review the principles and supporting attributes in WANO GL 2006-02, *Principles for a Strong Nuclear Safety Culture*.

### 4.2.1.2 Reactor regulating system transient

In a pressurised heavy water reactor, which was operating at 92 percent power with liquid zone levels at approximately 42 percent (average), the liquid zone water levels dropped rapidly, causing an automatic reactor scram on high neutron overpower and a subsequent turbine trip.

Liquid zone water levels are one of several reactivity control systems in the reactor regulating system. Neutron absorption is controlled by the varying of the light water content of 14 cylindrical compartments within the reactor and by the insertion of the control absorbers (control rods) into the core. The volume of light water can be controlled either simultaneously to achieve bulk neutron flux control or independently to achieve spatial flux control. The liquid zones act as a ‘cushion’ to maintain reactor power at a controlled level during on-line refuelling with fresh fuel in different areas of the reactor core.

The liquid zone water levels dropped rapidly because of two long-standing equipment problems. An ageing pressure transmitter associated with the helium gas pressure regulator
failed, resulting in high-pressure gas pushing light water out of their compartments. The helium pressure change was so rapid that water level control was outside the normal span of control for the reactor regulating system. A backup helium bleed controller should have responded to the increasing header pressure by opening the backup bleed valve, but the valve did not respond because it was in manual control and was only open approximately 10 percent. In this configuration (feed valve full open, backup helium bleed valve only open 10 percent), helium pressure provided the driving force to push water from the zones, inserting positive reactivity and increasing reactor power approximately 0.4 percent per second. The reactor power increase resulted in the reactor regulating system partially inserting control absorber rods—a step-back function; but before step-back had fully operated, both shutdown systems initiated on high neutron flux overpower protection and terminated the transient with an automatic reactor scram.

In addition to the failed pressure transmitter because of ageing, the risk of operating the backup bleed valve in manual control was not questioned or corrected. Its effect on the control of core reactivity for an extended period was not identified for corrective action in a timely manner. Placing this controller in manual was also contrary to recent operating standards for procedure adherence.

4.2.1.3 Reactor trip due to loss of power supply to reactor regulatory system

In another pressurized heavy water reactor, the reactor power inadvertently increased from 73 to 98 percent following a loss of electrical power to the adjuster rods (control rods) which incapacitated the reactor regulating system and caused an automatic reactor scram. The operator did not attempt to manually scram the reactor during the power transient. The unit had been operated at reduced power for several months with a peak flux configuration such that some of the central fuel channels were operating near full power. Later analysis identified that no fuel damage occurred because of this transient. Reactor scram setpoints were not reduced to 80 percent during prolonged operation at reduced power as required by technical specifications. The reduced scram setpoints would have limited the power increase during the transient.

The loss of power to the reactor regulating system was caused by fuse failures from a circuit breaker malfunction during preventive maintenance on the power supplies. Prior to the transient, an operator inappropriately inhibited the automatic boron addition system, perceiving that an automatic boron addition might occur because of power fluctuations from refuelling.
However, operating procedures did not authorise defeating the system in this condition. The operator further allowed reactor power to increase from 73 to 98 percent over an 11-minute period without taking action to stop the power increase or initiate a manual reactor scram. Management did not ensure that the reactor scram setpoints were reduced as required by technical specifications when operating the plant at reduced load. Also, management did not provide additional operational directions to operators to monitor or limit reactor power.

4.2.1.4 Reactivity disturbances due to actions on steam turbine bypass

In a PWR during rated power operation, a turbine trip occurred due to a relay failure. Reactor power automatically ran back to 30 percent as per design and steam was released to the condenser through the turbine bypass valves. Response to the event was undertaken using plant procedure I12, ‘Turbine tripped without SCRAM’, which was the appropriate operations procedure.

One-way communication used by the operator in charge of the secondary side systems, with no feedback from either the shift supervisor or the other operator, proved to be too informal and led to the operator’s mistake. In response to changing plant conditions, the operator in charge of the secondary side systems communicated with the other control room staff about his actions without getting any relevant feedback.

Three-way communications was not a control room expectation at that time. Without fully acknowledging and understanding one of the alarms, the operator decided to reinitialise the turbine bypass in order to prepare the turbine for synchronisation. This action caused the closure of the main steam to condenser bypass valves.

There was a loss of control room supervision and oversight during the event, contributing to this was a lack of communication of the roles and expectations of crew members when changing team organisation. As soon as the shift manager was aware of the situation he brought a third operator into the control room to take the place of the operator who made the mistake. This was done without discussing the situation either with the shift supervisor (deputy shift manager) or the other member of the shift team. Therefore, this person’s role was not identified and shift supervision mistakenly thought the person was the primary responder to plant events.

As the reactor temperature increased, one bank of control rods inserted below their very low limit. This initiated the appropriate alarm on the annunciator panel, which alerted the operators to this condition. In accordance with the alarm sheet, the operator started a manual boration
with the intent to subsequently raise control rods to recover sufficient reactivity margin. The alarm sheet had not been correctly updated in 1999 following corporate guidance, leading to a direct boration until the alarm disappears instead of borating according to the over insertion rate of control rods.

Below a specific threshold of power, rods cannot move automatically. As a result, the operator manually withdrew control rods. Manual boration was stopped when the alarm for ‘control rods below their very low limit’ cleared. This was the expected response when complying with the alarm sheet requirements. To compensate for decreasing neutron flux, dilution was initiated, as well as extraction of other banks of control rods. These actions were thought to be acceptable because the operators focused on the plant being critical as evidenced by being above the permissive threshold, P6, which actuates the switch from power range monitoring to source range. The operators did not use any other means to validate they were in fact critical, although the information ‘reactor critical’ was no longer displayed on the process computer screen. However this was not obvious to him due to the lack of any ringing sound when displayed information on the computer screen changes.

There is an accepted policy of allowing dilution and control rod withdrawal if the reactor is critical, but is prohibited if the reactor is subcritical. Following boron dilution and control rod withdrawal, the neutron flux started to increase rapidly, which triggered the alarm for doubling time less than 18 seconds. Reactor power rose to approximately seven percent power. The reactor had become subcritical and became critical again without the operations team being aware of the circumstances.

4.2.2 Events with reactors at start-up or at low – power

4.2.2.1 Manual trip due to control rod insertion

On 6 August 2006 during a reactor start-up after a periodic shutdown of an AGR, ineffective configuration control of control rod fuses resulted in the reactor being started with two trim rods still fully inserted into the core. Upon achieving criticality, core flux and temperature profiles were not as expected and the reactor was manually scrammed after it was identified that two trim group 1 control rods were still fully inserted into the core instead of being at their designated start-up positions.

When operators initially attempted to withdraw the coarse group control rods for reactor start-up, the rods did not move. The fuses for the control rod power supplies were not installed. The
fuses were removed during the outage for planned control rod interlock testing. Test personnel did not reinstall the fuses because they believed the fuses needed to be removed to support other control rod testing. However, the work order was signed off as complete with no information identifying that the fuses were not installed.

Two workers began to replace the coarse control rod fuses, but they also inappropriately removed two additional fuses to verify the fuse ratings for the coarse control rods. Removal of these two fuses resulted in the power supplies being de-energised to two trim group 1 control rods, which were partially withdrawn to their prescribed start-up positions. Control room operators were not aware that two trim group control rods had fallen into the core because plant design only indicates the actual position of the individual rods in the control rod group to be moved. Reactor start-up commenced without further verification of the control rod fuses. The reactor start-up identified abnormal core indications and discovery that two trim group control rods were still in the core.

Configuration control of the control rod fuses was not maintained during the outage and subsequent problem investigation. Test procedures and work documents did not accurately track the actual configuration of the fuses and the subsequent action to restore the rod control system after the aborted start-up.

4.2.2.2 Technical specifications for the reactor coolant system heat-up rate exceeded

On 28 May 2004 during a plant start-up of a BWR at the end of the core operating cycle (EOC), an uncontrolled reactor heatup rate occurred. The operating crew took nonconservative actions to maintain the reactor operating, instead of initiating a manual reactor scram.

The reactor coolant system (RCS) temperature was maintained constant at 50 degrees Celsius (122 degrees Fahrenheit) by maintaining the residual heat removal system (RHR) in the shutdown cooling mode, which should have been in its emergency core cooling system lineup. The shift supervisor did not follow the startup procedure as written and kept the RHR system in the shutdown cooling mode, as requested by the reactor engineer.

The operating crew was unaware that a positive moderator temperature coefficient existed at the EOC.
After the reactor was critical, the combination of the positive moderator temperature coefficient and the initial RCS heatup added a large amount of positive reactivity, resulting in the uncontrolled RCS heatup after core cooling from the RHR system was stopped.

Because of the excessive heatup, operators were not able to complete many of the start-up procedure actions. The reactor head vents remained inappropriately aligned to the drywell sump, when the start-up procedure requires the valves to be aligned to the steam lines. As a result, radioactive steam entered the drywell atmosphere. In addition, the drywell ventilation dampers inadvertently remained open during the start-up, when the valves are required to be closed. As a consequence, an unplanned radioactive release to the environment occurred. The radioactive release was below the operating limit and there was no hazard to the environment.

**4.2.2.3 Uncontrolled divergence leading to passage above 2 percent power**

A PWR was restarted after a one week unplanned outage. The plant had been operating approximately 25 percent of its planned fuel cycle duration. In preparation for making the reactor critical, the shift team and a safety engineer made reactivity balance calculations using two different tools.

The safety engineer was using a new computer tool that was qualified but not yet in application at the power plant. An 80ppm discrepancy in calculated reactor coolant boron concentration was found between these calculations. The operators initiated boron dilution, which was halted at 1450ppm. New reactivity balance calculations were made, using the approved procedures, which showed a 21ppm discrepancy, which was within the tolerance stated in the procedure. However, the approved procedures had an error because they were based on an incorrect spreadsheet, which was embedded in both the safety engineers’ and the operations’ procedures.

The spreadsheet was developed locally by the safety engineers group, validated for safety engineers’ use and later included in the official operations procedure after agreement by core engineering. The operators decided to insert one bank of control rods low enough to provide enough reactivity margin to avoid achieving criticality while diluting. This rod position was lower than the position referenced in the procedure. The operator subsequently initiated an additional reactor coolant dilution with a 19m³ water volume at a continuous flow rate of 20m³ /h based on the latest calculations that assessed criticality applying the inverse count rate method. The shift manager then left the control room to perform an unrelated task on unit 2.
Because discrepancies in identifying criticality parameters were experienced in the past, the safety engineer raised the possibility of an earlier criticality than calculated. When 16 m3 of water had been added to the reactor coolant, a reactor power threshold alarm occurred that indicated reactor power was increasing faster than expected and the dilution was stopped.

Although the operators experienced repeated differences between predicted and actual ‘estimated critical boration’ (ECB) during approaches to criticality, corrective action was not initiated. In addition, the guidance to conduct dilution did not comply with the requirement to reduce the dilution rate when reaching the critical concentration.

Criticality was not considered as a ‘sensitive transient’ by the operation department, however a third operator was added to the shift but without clear role definition and shift manager supervision was hampered by unrelated tasks.

The operators found that power was continuing to increase while the doubling time was decreasing from infinite to 40 seconds. The shift manager returned to the control room after being contacted. He directed the operators to insert control rods and to initiate boration of the reactor coolant. Reactor power continued to increase to 3.6 percent, thus exceeding the 2 percent limit required by the technical specifications for six minutes.

The reactor operator was not familiar with how to correctly interpret the doubling time instrumentation as it started to diverge from infinity. In addition, he did not fully understand how to interpret the reverse counting rate. It was the first time he performed an approach to criticality in the main control room. In addition, his predictions were not challenged within the team; and safety engineer warnings about a possible early criticality were not heeded.

4.2.2.4 Unplanned reactor operations below the point of adding heat

On 4 February 2005 with the reactor from a PWR being held critical between 1 and 5 percent reactor power for planned maintenance, the operating crew did not observe power drop out of the specified range. Reactor power decreased nearly five decades over a 40-minute period and remained below the point of adding heat for about two hours. Xenon continued to build in following the power reduction, adding negative reactivity and causing reactor power to decrease further.

The responsible operator did not scan intermediate power range instruments and inappropriately focused on reactor coolant delta temperature indications and power range nuclear instruments. These instruments remained fairly constant and are more appropriately
used to monitor reactor power at or near rated power. Another reactor operator, returning to the control room from an assignment, observed that reactor power was in the intermediate range and notified the control room crew. The reactor operator inappropriately focused on average core temperature, core delta temperature and power range instrumentation as the primary indicators of reactor power, which remained fairly constant as the steam generator power operated relief valves were in pressure control mode. The operator did not observe the start-up rate and the intermediate range nuclear instruments. As a result, the reactor operator did not recognise that reactor power decreased approximately five decades in the intermediate range to $1E^{-10}$ amps, which is below the point of adding heat and subcritical.

When this condition was recognised, the operator added positive reactivity twice with outward control rod movement and three dilutions of approximately 200 gallons (760 litres) each. These reactivity changes occurred over 40 minutes. The positive reactivity additions were announced by the operator, acknowledged by the unit supervisor but were not questioned and peer-checked by another reactor operator. The unit supervisor was distracted while analysing the cause of an earlier problem and did not become aware of the lower power level until informed by the operator. At this point, intermediate range nuclear power had further decreased to $7.5E^{-11}$ amps. Once aware that power was far below the prescribed band, the operating crew did not take the conservative action to shut down the reactor. Instead, a decision was made to withdraw control rods three steps to raise reactor power. Reactor power was returned to 3 percent. Reactor power was outside the prescribed power band for about two hours. The operator did not monitor the most appropriate indications of reactor power and lacked knowledge and experience for low-power reactor operations. The effect of xenon changes and their effect on core power were not anticipated. In addition, supervisory oversight and procedure guidance for low-power operations was insufficient to prevent or mitigate the power transient. The evolution prejob briefing was insufficient and the operating crew declined to participate in just-in-time simulator training to practise the evolution.

4.2.2.5 Reactor protection actuation during reactor startup

On 10 May 2004 during a start-up of a PWR after a refuelling outage and preparation for low-power physics testing, two operating range nuclear instruments unexpectedly tripped, causing an automatic reactor scram. The neutron flux control system is divided into two subsystems: the start-up range and the operating range. Both the start-up and operating range reactor power alarms were set to $9.8E^{-3}$ percent. The selection of the working range—start-up or operating—is made automatically by the nuclear instruments.
After shift turnover, a reactor operator withdrew control rods to increase reactor power for physics testing. One operating range channel alarmed at 9.8E-3 percent. However, the start-up range instruments that operators were monitoring indicated reactor power was only at about 4E-4 percent power. A safety engineer recommended that the crew increase the operating range trip setpoints; and as an operator started to change the trip setpoints, a second operating range channel tripped causing the reactor scram.

The effect of the new reactor core on nuclear instruments was not anticipated and the operating crew did not monitor all available core power indications. Supervision did not provide sufficient oversight during the reactor start-up especially as this was the operator's first reactor start up.

4.2.3 Events during power increase

4.2.3.1 Reactor trip by overpower Delta – T following flux deformation

On 17 November 2003, a PWR reactor automatically scrammed when an overpower trip setpoint was exceeded because of an operator-induced error in trying to control core delta flux (imbalance) during a power increase from 30 to 100 percent power.

The operator increased power from 30 to 100 percent at a rate that did not consider xenon burn-up effects. The flux imbalance moved towards the top of the core at the same time as xenon was burning out in the top of the core from previous load changes. As a result, the increased core flux in the top of the core kept imbalance toward the top of the core. The operator attempted to correct the flux imbalance by diluting the boron concentration in the reactor coolant system (RCS). The RCS was subsequently diluted too much (four dilutions) and the control rods automatically inserted into the core below the control rod insertion limit. The operator did not take action to add boron to the RCS as directed by the alarm procedure to restore the control rods to their normal positions. The operator focused too much on moving the corrective term from 45 MW to zero (method of controlling imbalance), instead of following the alarm procedure directions. When a supervisor arrived in the control room, he directed the operator to add boron to the RCS, but the action was too late to restore the flux imbalance before the automatic reactor scram.

An ineffective shift turnover did not communicate the recent core operating history to identify that core power was increasing because of xenon burn-up. The Monday morning shift turnover did not communicate problems in controlling imbalance between 30 and 100 percent load.
changes during the previous weekend. The operator was alone on the unit and shift supervisors were not in the control room because they were conducting a shift turnover briefing. This is particularly important because it was the first time the operator performed a power increase and stabilisation and he was unfamiliar with these plant conditions.

4.2.3.2 Reactor operation in an unanalysed region

On 9 July 2006 in a BWR, following a power reduction for a control rod pattern sequence exchange, the reactor was operated periodically in an unanalysed region above the maximum extended operating domain (MEOD) boundary for several periods over a two and one-half hour time frame. This condition was not recognised for more than 24 hours when reactor engineering personnel reviewed evolution data. The MEOD is the analysed region of reactor operation. It consists of the normal operating power-to-flow map region supplemented by special analyses with increased core flow (up to 105 percent of rated flow) and the maximum extended load line limit analyses (MELLA) that support operation above the 100 percent load line. The upper limit of these analyses is the MEOD boundary.

Operations and reactor engineering personnel adjusted the control rod pattern using an approved reactivity plan. The plan involved a power reduction to 85 percent, a series of control rod movements, scram time testing and a single ramp back to full power by increasing core flow. Reactor engineering personnel had a goal to accomplish the evolution with one ramp back to full power because it was perceived that this was the best practice. Because of core conditions, this required a load line in excess of the 110 percent of the administrative limit. When operators increased reactor power, they had to stop when one control rod would not move. The control rod problem delayed completion of the reactivity plan by 12 hours and there was an additional delay of 2 hours. During the 14-hour delay, core reactivity changed because of the burnout of xenon, but the reactivity plan was not changed or modified. Shortly after control rod withdrawal resumed, the plant computer alerted the crew that the 110 percent administrative load line limit was exceeded. The operators and reactor engineer believed that if reactor power was maintained below the 112.9 percent load line, the MEOD boundary would not be exceeded. However, with reactor recirculation flow at 72 percent, the MEOD limit was 92.62 percent power and the limit imposed by staying below the 112.9 percent load line was actually 92.97 percent power. During this time, fission product poisons in the reactor core (mainly xenon-135) burned out, adding positive reactivity and increasing reactor power, thereby exceeding the MEOD boundary limit.
Reactor engineering and operations management prepared and approved a flawed reactivity plan. The plan intentionally exceeded station administrative limits without providing appropriate barriers, did not address activities that could substantially affect core conditions, did not contain termination criteria and was inconsistent with station expectations.

4.3 RECOMMENDATIONS ISSUED BY WANO FOLLOWING THESE EVENTS

When the WANO had gathered all the information regarding the events mentioned above and had analysed them with the root cause analysis, the following recommendations were issued. All WANO members need to address all these recommendations.

This means that each recommendation must be challenged by local plant policies and procedures. If gaps exist between the recommendations and the local plant policies, corrective actions must be defined. These actions must be communicated to the WANO operational center, and a follow up of the implementation and accuracy of the corrective actions is done by WANO during frequent WANO peer reviews.

4.3.1 Recommendation 1 : standards and expectations

Clear directions and standards should be provided to station personnel. These standards and directions should include error reduction tools. More precisely the guidance rules must at least contain the following:

- All reactivity changes and mode changes must be directed by detailed operating procedures to prevent errors and misunderstandings. It is specified when procedures need to be “in hand” for reactivity manipulations.
- All reactivity changes are made in a controlled manner. The operational procedures specify which backup and redundant nuclear instrumentation, as well as other plant parameters (pressures, flows, temperatures) shall be monitored by the operators when reactivity changes are made. Reactivity change is done by one method at a time.
- Reactor operation at low – power levels for extended periods of time is discouraged.
- The addition of positive reactivity (especially by withdrawing control rods) in response to plant anomalies, caused by secondary plant transient must be discouraged.
- The procedures specify which error-reduction tools are used in conjunction with procedures when controlling core reactivity.
4.3.2 Recommendation 2 : Crew supervision

The shift supervisors direct core reactivity changes and make sure that conservative decisions are made during plant operations and fuel handling. More specifically the following points must be implemented:

- Supervisors provide oversight for core reactivity changes. Operators with little or no reactor startup experience are specifically monitored by supervision during reactivity manipulations.
- During reactivity manipulations, shift operations supervisors are not assigned non-operational tasks, in order that they are not distracted from proper oversight over the reactivity manipulations.
- Supervisors make sure that the operators conducting reactivity manipulations have received the proper training, and that they understand their roles and responsibilities.
- The control room environment is managed to minimise distractions.
- No reactivity changes will be done during shift turnover of shift crew briefings.

4.3.3 Recommendation 3 : Reactor engineering

Clear roles, responsibilities and procedure guidance must be established for the interface between reactor engineers and the operations organisation. Following elements are addressed:

- Plans for (significant) reactivity changes are reviewed and approved by station and shift operations management, as well as reactor engineering personnel. If power changes are delayed, the new plant conditions are taken into account in the reactivity plan.
- Reactor engineers are available to assist operators during reactivity changes.
- Before reactor start-ups, core criticality predictions are determined and independently verified.
- Core operating cycle information (reactivity coefficients, burnup characteristics, impact of design changes) is provided to operators before start – up. Relevant information is incorporated into procedures, simulator training and simulator modelling if possible.
4.3.4 Recommendation 4 : Training

The operators receive initial and frequent recycling training on reactor physics fundamentals, core characteristics over core life and the operation of reactivity control systems during normal, abnormal and emergency operating conditions. Following elements must be incorporated:

- Reactor theory on core poisons (boron, xenon, samarium, gadolinium), how they are produced / consumed in the reactor and the effects they have on reactor power.
- Variation of core reactivity coefficients over core life and what actions the operators can take to control the reactor.
- Include in training programmes the station operating experience, as well as the external information.
- Reinforce management expectations during training sessions to place the plant conservatively in a safe condition when unexpected plant conditions exist.
- Reactor engineers participate in simulator training with shift operating crews at least once per refuelling cycle.

4.3.5 Recommendation 5 : Equipment and work coordination

Reactivity control equipment and monitoring equipment must be verified for deficiencies, and if deficiencies are found, they must be promptly resolved / repaired.

- Equipment deficiencies that could impact reactivity monitoring and control are focused on during work planning and execution activities.
- When maintenance work is performed on reactivity control equipment, configuration control is maintained to ensure that the system or component will be returned to its proper state
- Eliminate operator workarounds related to reactivity control equipment as soon as practical.

4.4 ANALYSIS OF THE RECOMMENDATIONS WITH REGARD TO NPP DOEL

In this paragraph each of the recommendations will be challenged with regards to applicable work methods and procedures at the power station of Doel. If the recommendation is not met, corrective actions will be suggested to be compliant with the WANO recommendation.
For ease of following, the recommendations will be addressed as mentioned above, bullet by bullet.

Before these recommendations will be challenged, an overview of the present reactivity management methods will be given.

### 4.4.1 Present reactivity management methods and procedures at Doel.

In this paragraph an overview will be given of the present rules and procedures that are applicable to the Doel Power Plant. This will help the reader to better understand the improvements that will be defined later to be compliant with the recommendations from the WANO SOER.

The base document that describes the rules regarding reactivity management is the procedure EXPL/O/07 (SAP reference : 1000746275) which bears the title “Control Room Culture”.

This procedure describes the expectations regarding serenity in the control room of the nuclear power plant of Doel, the expectations during normal operation and during incidents or accidents, and the commandments for reactivity management. These expectations are trained during the simulator sessions, and are used as a basis during field observations by the management. These field observations check the current ongoing practices with the expectations, if gaps are detected with regard to these expectations, immediate feedback is given to the observed personnel.

The commandments are the following:

- Each reactivity change will happen by use of a procedure or an expert user sheet
- During reactivity increase, the operator will only influence one parameter (either the position of the control rods, either the boron concentration). It is strictly forbidden to simultaneously change the position of the control rods and to dilute.
- Reactivity changes are monitored closely to verify that the expected results really occur. The following parameters must be used for monitoring:
  - Average temperature of Primary Coolant circuit
  - Delta T over the core
  - Instrumentation power changes (intermediate measurement changes)
  - Insertion limits
  - Overlap of the control rods
Discrepancy between requested position of control rods and actual position of control rods
- Boron concentration in the primary coolant circuit and in the pressurizer
- Axial offset

- Reactivity changes are priority, no other tasks are being performed while doing reactivity changes by shift supervisors
- Operating the nuclear power plant while maintaining the control rods on manual is considered a risky operation. Therefore this mode is avoided as much as possible.
- All distractions are to be avoided in the control room while doing reactivity changes, therefore access to the control room is strictly limited.
- Each reactivity calculation is done by two different persons, independently from each other and using different methods for calculating
- For each power modulation, a formal prejob briefing is being held, with the use of JIT (just in time) sheets.
- It is not permitted to manage a transient from the secondary side of the plant (e.g., load drop,…) by adding positive reactivity

For making the reactor critical, specific procedures exist for each reactor unit which describe the necessary steps for making the reactor critical.

These procedures are:
- 1.G.02 for Unit Doel 1 (SAP reference 10000025863) : Start group from hot standby to 100%
- 2.G.02 for Unit Doel 2 (SAP reference 10000025861) : Start group from hot standby to 100%
- F-RE-01 for unit Doel 3 (SAP reference 10000022199) : Making the reactor critical
- F-RE-01 for unit Doel 4 (SAP reference 10000024710) : Making the reactor critical

These procedures contain instructions for calculating the critical boron concentration based upon a reactivity balance. They also contain instructions for actions that have to be done before the reactor can be made critical. These preliminary actions are for instance organize a prejob briefing.

The procedures contain also the instructions to make the reactor critical. These contain initial conditions which have to be verified, instructions for making the reactor critical either by dilution or by retracting the control rods.
These instructions are written as step by step instructions. Each step need to be performed, and signed by the operator before the next instruction may be executed. This is to ensure that nothing is forgotten, and that all the safety margins are respected.

In the following paragraphs the SOER recommendations are challenged with regard the above mentioned procedures and training that is organized in Doel, to see if additional improvements are necessary.

4.4.2 Recommendation 1 – Standards and expectations

- All reactivity changes and mode changes must be directed by detailed operating procedures to prevent errors and misunderstandings. It is specified when procedures need to be “in hand” for reactivity manipulations.
  "Since beginning of 2008, a new version of the management expectations within the operations department have been written that specifically addresses the above issue. More specifically “every reactivity change must be done by procedure or by Expert User Sheet”. This is specified in §4.1 of the procedure “Control Room Culture” (EXPL/O/07 : 1000746275)

- All reactivity changes are made in a controlled manner. The operational procedures specify which backup and redundant nuclear instrumentation, as well as other plant parameters (pressures, flows, temperatures) shall be monitored by the operators when reactivity changes are made. Reactivity change is done by one method at a time.
  "In the management expectations an overview is given of the instrumentation equipment that must be used to monitor the reactivity changes. If the plant does not react as expected, it is the task of the operators to take the plant to a safe known situation, as described in the management expectations.
  This is specified in §4.1 of the procedure “Control Room Culture” (EXPL/O/07 : 1000746275)

- Reactor operation at low – power levels for extended periods of time is discouraged.
  "At the plant of Doel, operation at low – power levels is limited to maximum 28 days. When operating at low – power several SCRAM limitations are lowered in order to stop rapidly an unwanted evolution. This is documented specifically in a procedure for operation at lower power (see extract EXPL/O/20 chapter 5 : 10000750094). This mode of operation is possible in summer time for longer periods, due to legal limits on coolant water rejection to the river Schelde, therefore limitation on power production is possible. Long term operation at very low power with critical reactor, but none or very
few electrical power is not yet described in an operational procedure. This is however necessary because the reactivity feedback at this operating point is, just as with the physical tests of the reactor, different from the reactivity feedback at normal power operation. Also during start or stop operations for an outage there is special focus with the reactor at a nuclear thermal power of 3 – 5%. Prejob briefings are held before power modulations. Power modulations is also an integral part of the simulators sessions for the operators. (see extract EXPL/O/20 chapter 5 : 10000750094)

**ACTION**: Revise procedure so that operation at very low power (<15%) is integrated

### 3 MAXIMAAL TOEGESTANE FPPR-TIJD

De totale duur, gecumuleerd over de volledige cyclus, van LANGDURIGE WERKING OP VERLAAGD VERMogen enerzijds en van STRECHOUT-WERKING beneden de 95 % NTV anderzijds, is beperkt tot 4 weken (28 dagen).

Volgende gevallen worden niet meegerekend in de boekhouding:

- Uitzonderlijke werking op verlaagd vermogen omwille van correctief onderhoud t.g.v. problemen opgekomen tijdens de beschouwde cyclus (mits akkoord van het E.O.).
- De werking op verlaagd vermogen tijdens de eerste stijging naar normaal vermogen na herlading.
- Periodes van warme stilstand (zie bijlage 1)

### 5 ACTIES BIJ FPPR

#### 5.1 VERLAGING VAN DE INSTELWAARDEN VAN DE PROTECTIES

**5.1.1 Noodstop door hoge flux vermogenketens**

- Van zodra de aaneengesloten duur van LANGDURIGE WERKING OP VERLAAGD VERMogen meer dan 15 dagen bedraagt, moet de drempel voor noodstop door hoge flux vermogenketens ingesteld worden op ten hoogste 9% NTV boven het vermogensniveau waarop uitgebaat wordt.

- Tijdens de STRECHOUT-WERKING moet op het ogenblik dat 85% NTV bereikt wordt, de drempel voor noodstop door hoge flux verlaagd worden tot ten hoogste 94% NTV. Daarna moet de drempel verlaagd worden naarmate het thermisch vermogen daalt, tot ten hoogste 9% NTV boven het vermogensniveau waarop uitgebaat wordt, en dit ten minste in stappen van 15% NTV.

- De aanpassing van de noodstopdrempel wordt via TBI geborgd en aangeduid in de KZ.

**5.1.2 Noodstop door ΔT-OP**

- Van zodra de aaneengesloten duur van LANGDURIGE WERKING OP VERLAAGD VERMogen meer dan 15 dagen bedraagt, moet de drempel voor noodstop door ΔT-OP ingesteld worden op ten hoogste 8,9% NTV boven het vermogensniveau (P % NTV) waarop uitgebaat wordt.

- Gedurende STRECHOUT-WERKING is aanpassing van de drempel voor noodstop door ΔT-OP niet vereist op voorwaarde dat:
  - de regelstaven boven de insertielimieten, geldig op 100 % NTV, blijven
  - EN de boorconcentratie kleiner blijft dan 100 ppm.

- De aanpassing van deze noodstop drempel wordt via TBI geborgd en aangeduid in de KZ.
The proposed change to the procedure for operation at < 15% Nominal Thermal Power is given hereunder:

6.4 UITBATING-OP ZEER LAAG-VERMOGEN

6.1 VOORWAARDEN: VOOR-UITBATING-OP ZEER LAAG-VERMOGEN

Onder zeer laag vermogen wordt verstaan een vermogen kleiner dan 15% NTV.

Langdurige uitbating op zeer laag vermogen moet vermeden worden. Enkel in de volgende gevallen mag er gedurende lange tijd op zeer laag vermogen uitgebad worden:

<table>
<thead>
<tr>
<th>Toestanden</th>
<th>Maximale toegelaten tijdsperiode</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Tijdsopstapmanoeuvres (vb. onder 15% moeten staan omdat men wacht op een herstelling, respecte speel van schelkundige parameters)</td>
<td>24 u.a.</td>
</tr>
<tr>
<td>2. Fysische testen (reactorkritisch)</td>
<td>18 u.a.</td>
</tr>
</tbody>
</table>

Bij uitbating op zeer laag vermogen worden de volgende voorwaarden om de 6u geëvalueerd op hun geldigheid, indien aan deze voorwaarden niet meer voldaan raadpleeg DHDB (of WR2 bij afwezigheid) en Afdelingshoofd. Hierop wordt Bijlage 3 ingevuld.

6.2 REGELS BIJ-UITBATING: OP ZEER LAAG VERMOGEN

Bij langdurige (> 12 u) uitbating op zeer laag vermogen:

- Blokkleider primair groep (P12) blijft aan de primaire pomp.
- Een blokkleider secundair of een blokkleider niet belast met de uitbating van de andere groep blijft binnen de lijnen van de KZ en is beschikbaar op simpel vraag.
- Een secundaire transiet mag enkel primair opgevangen worden door de inbreng van reactiviteit.
- Indien er voor temperatuurcontrole staven moeten getrokken worden mag men maximaal 2 stappen trekken per.handleiding, daarna verifiëert met de invloed en laat men de transiente stabiliseren alvorens opnieuw staven te trekken.
- Δ\(\Delta\) of axial offset moet binnen de 5% band gehouden worden (zie ref 2).
- Bij elke primaire of secundaire manipulatie is 2 weg communicatie en peer check verplicht.
- Extra aandacht voor de automatiseren die in deze toestand anders reageren of buiten dienst zijn.

- The addition of positive reactivity (especially by withdrawing control rods) in response to plant anomalies, caused by secondary plant transient must be discouraged.

This is covered in operational procedure "Control room culture" rule number 12: “It is not allowed to respond to a secondary transient by adding positive reactivity, especially not by pulling the control rods manually.” (see extract chapter 4 of EXPL/O/07 : 10000746275)
The procedures specify which error-reduction tools are used in conjunction with procedures when controlling core reactivity.

The use of Just In Time sheets, Expert User Sheets and prejob – briefings are described in the operational procedure “Control Room Culture”, rule number 1: “Every change in reactivity is done by the appropriate procedure or Expert user Sheet. The operator informs the Shift supervisor or Shift Reactor Operator of the planned reactivity change. The eight Human Performance error – reduction tools that are applicable are mentioned in the Management Expectations EXPL/O/100: (SAP reference 10000746309). These Human Performance error – reduction tools are:

- Pre job briefing
- Self checking
- Independent verification
- Use of procedures and adherence to procedures
- Effective communication (3-way communication)
- Conservative decision making
- Post job briefing

While these HU tools are described and trained, observations of station personnel have shown that further training and follow up is necessary to make sure that these HU tools are used in all situations.

**ACTION:** Follow up on performance of use of HU tools

### 4.4.3 Recommendation 2 - Crew Supervision

Supervisors provide oversight for core reactivity changes. Operators with little or no reactor startup experience are specifically monitored by supervision during reactivity manipulations.

The role and responsibilities of the supervisors during reactivity changes is described in the operational procedure “Control Room Culture”, rules 1 and 8, namely that shift crew supervision has to be performed during normal control rod movement and during dilution in case of power change. The new operators have to follow first an operator
training course with a finalising operators license exam. After this exam the operator is in a period of shadow training where he may not perform autonomously operator actions. After this period, and when the operator is at least 3 years working in the power plant, is he allowed to perform autonomously operator actions. For every reactivity change a peer verification is done by the shift crew supervisor.

- During reactivity manipulations, shift operations supervisors are not assigned non-operational tasks, in order that they are not distracted from proper oversight over the reactivity manipulations.

This is as yet not an explicit management expectation. The operator must inform the supervisor before planned reactivity changes. During a stop or start – up of the power plant, the supervisor is only active with operational tasks. This expectation must be written more explicitly.

**ACTION:** Revise procedure EXPL/O/07 to make this rule more concrete and communicate about the change.

- Supervisors make sure that the operators conducting reactivity manipulations and maintenance personnel working on equipment for reactivity control have received the proper training, and that they understand their roles and responsibilities.

The personnel that maintains the equipment for reactor control are trained within their maintenance service. At first the maintenance personnel is only observing the maintenance actions performed by an experienced colleague, before they may maintain the equipment under supervision of their experienced colleague. The management expectations of Operations are explained to the maintenance personnel. The contractors receive a four – day training in a work simulator, where they must perform several maintenance activities under real conditions. Contractors who have the necessary experience are used for these critical maintenance activities. Their experience is tested on before hand with an on hands job, and specific pre job briefings are given. To improve the supervision done by Doel personnel, mixed teams of contractors and Doel personnel are formed. The initial training for all Doel personnel comprises a 5 day training program explaining the principles of a PWR power plant, as well as criticality. For the maintenance personnel responsible for the maintenance on the reactor instrumentation, an additional training program is followed consisting of reactor protections, nuclear instrumentation and for work preparators the course of reactor theory of Petten is given.
Operators receive a yearly refresher training (2 weeks on simulator and 2 weeks on reactivity and use and content of procedures) with the participation of their shift supervisor as observer. The shift supervisor debriefs also the simulator training session.

- The control room environment is managed to minimise distractions

The operational procedure “Control room Culture” stipulates that during reactivity changes there must be serenity in the control room. Access to the control room is therefore strictly limited to necessary personnel. Observations of this expectation show that in certain cases, access to the control room was granted while it was not appropriate. Further restrictions should be considered.

**ACTION:** Consider options to limit access to control room more strictly and implement these options.

- No reactivity changes will be done during shift turnover of shift crew briefings.

This is also covered in the procedure “Control room culture” by rule number 10. During shift turnovers, no reactivity changes are executed. If the power plant in start up, and the operations are ongoing for making the reactor critical, it is allowed to set the reactor in the proper state to approach criticality by the end of the shift. This means that if the reactor is being made critical by retracting the control rods, operator personnel may dilute to the correct critical boron concentration, of in the case that the reactor is being made critical by dilution, then the control rods may already be placed in the proper position. All these steps need to be done by use of the appropriate procedure, and the new shift will commence with a pre job briefing before continuing with the criticality.

4.4.4 Recommendation 3: Reactor engineering

- Plans for (significant) reactivity changes are reviewed and approved by station and shift operations management, as well as reactor engineering personnel. If power changes are delayed, the new plant conditions are taken into account in the reactivity plan.

When operational procedures regarding change of reactor core or reactivity management need to be reviewed, the reactor engineers are one of the responsible persons that must approve the new procedure (either as author, either as approver). Power variations / modulations are rarely asked at the power plant of Doel (base load
operation), but if this should occur, the rules are written in procedure INST/46 (SAP reference: 10000004957).

2.6.1 Standaard modulatie

Zolang boorconcentratie in RC-kring boven 200 ppm kunnen de productielijnen volgende modulatie uitvoeren vanaf vollast:

- Vermengdaling:
  - Doel 34: max 500 MWatt aan max 10 MWatt/min;
  - Doel 12: max 200 MWatt aan max 4 MWatt/min

- Periode op deellast: minstens tot 6 uur na aanvang van vermengdaling (zodat Xenonpiek voorbij is als er terug gestegen wordt in vermogen).

- Terugkeer naar vollast:
  - Zolang boorconcentratie in RC-kring boven 500 ppm:
    - max 10 MWatt/min (Doel34)
    - 4 MWatt/min (Doel 12).
  - Als boorconcentratie in RC-kring tussen 200 en 500 ppm max vermogen gradient dalend van:
    - 10 MWatt/min bij 500 ppm tot 5 MWatt/min bij 200 ppm (Doel34)
    - 4 MWatt/min bij 500 ppm tot 2 MWatt/min bij 200 ppm (Doel12)
  - Min periode op vollast voor nieuwe vraag tot modulatie: 36 uur (zodat Xenontransient grotendeels voorbij)

Opmerking: modulaties die vallen buiten limieten van standaardmodulatie (bv. modulatie als boorconcentratie in RC-kring onder 200 ppm of zelfs tijdens stretch-out zijn niet a priori uitgesloten, maar dienen wel speciaal bekeken door diensthoofd Bedrijf of (WR2). Diensthoofd Bedrijf zal evalueren of overleg nodig is met KAM Fuel.

- Reactor engineers are available to assist operators during reactivity changes.

In the present organisation, the reactor engineer as such doesn’t exist in our present organization. This role is divided between the operation engineer specialized in reactor engineering and the head of the fuel division or his deputy. Each reactivity change plan is written by the Operations Department and verified by the Operation engineer specialised in Reactor Engineering.

However, the roles and responsibilities between the Operation engineer specialised in Reactor Engineering and the Fuel Department Head (or his deputy) for Reactivity Management actions are not clarified.

**ACTION:** Clarify role and responsibilities with regard to reactor engineer

- Before reactor start-ups, core criticality predictions are determined and independently verified.

Every time the reactor is going to be made critical, two independent criticality calculations are made. One is calculated based on the paper curve book, the other is based on an excel developed computer model. The deviation between the calculations may be maximally 20 ppm for the reactors of Doel 1 and Doel 2, and maximally 10 ppm
for the reactors of Doel 3 and Doel 4. If deviations between the two calculations is larger, the calculation must be remaid by the same persons, but assisted by shift supervisor in order to identify the error. If there exist still deviations, the exempts of Operations are asked for additional advise. Normally this does not happen often, because the criticality calculations are trained every time on the yearly simulator training sessions, and each week by the early shift on Sunday.

- Core operating cycle information (reactivity coefficients, burnup characteristics, impact of design changes) is provided to operators before start – up. Relevant information is incorporated into procedures, simulator training,…

Before startup, the revised curve book is handed over to the reactor engineer by the Engineering Office Tractebel Engineering. These curves are prepared by Tractebel Engineering and are verified by the Operations Department. For every initial training, the most recent curve book is being used. Also for the training sessions on the simulator the most recent curve book is being used, and is complemented with some of the curves from the first cycle of Doel 4. At present it is not yet possible to implement the actual parameters in the simulator. A project is currently being realised to upgrade the operator simulators, which will allow to revise the core models on a yearly basis.

4.4.5 Recommendation 4 : Training

- Reactor theory on core poisons (boron, xenon, samarium, gadolinium), how they are produced / consumed in the reactor and the effects they have on reactor power.

As part of the 5 year Operator Training Package ref: PERS/O/04, after 2 years as field operator, a Control Room operator is trained during 18 months. After this he has to follow an on-the-job training with an experienced operator.

In the initial and continuing training programmes, the effect of B, Xe en Sm are treated in the training courses and are explained on the simulator of Essen. Each of the reactivity effects are being treated. The effect of Gd is at present not part of the training course. Gd is only used in the fuel of the reactors of Doel 3 and Doel 4.

Objectives include items such as effects of changes in reactor temperature on reactivity and reactor poisons and their effect on core reactivity.
Operators receive a yearly refresher training (2 weeks on simulator and 2 weeks on reactivity and procedures) with the participation of their shift supervisor as observer who debriefs the simulator training session.

However, the Units 3 & 4 simulator configuration is not up to date with the current Unit configuration, for example: the panels are different and some alarms are not provided on the simulator.

**ACTION**: A project is currently going on to rehost the simulators of Doel 12 and Doel 34, so that the simulator is up to date with the current unit configuration.

- Variation of core reactivity coefficients over core life and what actions the operators can take to control the reactor.

  This is part of the initial training courses in Doel. This is visualised during the practical exercises in the simulator of Essen. During recycling courses of the reactor regulation, special attention is given to this part. Once the simulator of Doel has been upgraded, the new core reactivity coefficients over core life can be implemented in the simulator, so that the training will happen with the latest data.

- Include in training programmes the station operating experience, as well as the external information.

  Experiences from the own power plants is used to create an awareness amongst future operators of possible problems one can encounter, how to avoid these problems and how to react when these events arise. An example is the 4l incident that happened on Doel 4. Every year there are special training courses organised for the operators on the simulator regarding approach to criticality and events of unwanted criticality. A new set of management expectations regarding reactivity management will be written based upon the operating experience, the WANO Guideline regarding reactivity management, benchmark with worldwide good performers and the recommendations from this SOER 2007 – 1.

  **ACTION**: Revise the management expectations (with focus on reactivity management)

- Reinforce management expectations during training sessions to place the plant conservatively in a safe condition when unexpected plant conditions exist.

  *When during training sessions on the simulator a situation occurs where the power plant is in an abnormal situation, the operators are encouraged to stop the power plant*
(which is the safest operating mode). These expectations are put in the operational procedure of EXPL/O/07. However these expectations must still be repeated, so that they are soaked in by the personnel, and that it thus becomes part of their trained behaviour. The training program must be revised on a frequent basis (2 yearly) to give focus on these expectations where gaps are observed.

**ACTION :** Evaluate and adapt training program with regards to management expectations taking into consideration observations of gaps

**ACTION :** Repeat management expectations on a frequent basis so that they become second nature

- Reactor engineers participate in simulator training with shift operating crews at least once per refuelling cycle.

  The reactor engineers and exempts follow each year 4 weeks of simulator sessions and are present during the physical tests of the reactor.

4.4.6 Recommendation 5 : Equipment and work coordination

- Equipment deficiencies that could impact reactivity monitoring and control are focused on during work planning and execution activities. Proper priority is given to solving these deficiencies.

  The priority of maintenance repairs is fixed on the daily coordination meeting of the plant. At this meeting an exempt of Operations and an exempt of Maintenance are always present. It is the responsibility of Operations to assess the urgency of the repairs and to make an evaluation of the impact of the repairs on the functionality of the other reactivity control systems. A holdpoint is fixed before the reactor is made critical. At this holdpoint a check of all the pre requisites is formally done and documented.

  However observations in the field showed that :

  - In the Control Room of the Unit 4 there were 14 red sticks on the main panel and another 5 of them on the Safety System panel, marking that some kind of deficiency occurred to the equipment.

  - 63 Temporary Instructions were found in the Control Room of the Units 1 & 2. 26 of them have an impact on Nuclear Safety and 9 on the operators’ work.
- 54 Temporary Instructions were found in the in the Control Room of the Unit 4. 26 of them have an impact on Nuclear Safety and 17 on the operators’ work.

- The Station does not have a formal process where degraded equipment is flagged and prioritised for Reactivity Management impact.

There is a list of workarounds concerning long standing control equipment issues. For example, the electrical parts of the control rod drive mechanisms were replaced in 2005 (Unit 4) and in 2006 (Unit 3) but the system malfunctions and raised regularly notifications (12 notifications in Unit 3, 20 notifications in Unit 4) since the implementation of the new system. So far this problem has not been solved.

**ACTION:** establish an action plan to solve this long standing problems, and prioritize them according to impact on reactivity control

- When maintenance work is performed on reactivity control equipment, configuration control is maintained to ensure that the system or component will be returned to its proper state

  According to the operational procedure of tagging, there is an explicit expectation to perform an independent verification of the untagging of the circuits related to reactivity (CV, DW, PB, SI, EA, RJ).

  Maintenance does have an operational procedure which describes for which tasks extra verifications, risk analyses,… must be done.

  During periodic testing of the T1 measurement chains, there is a verification of the accuracy of the signals. On plants of Doel 1 and Doel 2 this verification is done by comparison with the redundant measurements. On Doel 3 and Doel 4 this is done by monitoring the as found and as left values of the measurement chain. Identification of equipment having an impact on reactivity will be done and will be encoded in SAP (the work management system of Doel), so that necessary focus can be given to deficiencies to these equipments. This will be done by the RCM (Reliability Centered Maintenance) project, currently ongoing at NPP Doel.

  **ACTION:** Follow up of RCM project and encode equipment with impact on reactivity in SAP

- Eliminate operator workarounds related to reactivity control equipment as soon as practical.
A list of all the temporary operational instructions is available within Operations. These temporary operational instructions are in fact deviations that exist within the plant, that can't be solved while the plant is in operation. These deviations must be resolved during the next outage, hence the name temporary operational instructions. Since these instructions are deviations with regard to the design and normal operations, and thus the procedures, this list must be maintained short. It is the responsibility of Maintenance and Engineering Support to solve these temporary operational instructions according to priorities set by the management.

4.5 SUMMARY OF CORRECTIVE ACTIONS WITH REGARD TO SOER 2007-1

Following actions must be implemented in order to be compliant with the recommendations mentioned in the SOER:

- Revise procedure EXPL/O/20 so that operation at very low power (<85%) is integrated
- Follow up on training regarding HU tools
- Revise procedure EXPL/O/07 to make this rule more concrete and communicate about the change
- Consider options to limit access to control room more strictly and implement
- Clarify role and responsibilities with regard to reactor engineer
- Revise the management expectations (with focus on reactivity management)
- Evaluate and adapt training program with regards to management expectations taking into consideration observations of gaps
- Repeat management expectations on a frequent basis so that they become second nature
- Establish an action plan to solve this long standing problems, and prioritize them according to impact on reactivity control
- Follow up of RCM project and encode equipment with impact on reactivity in SAP
5 CONCLUSIONS

This thesis reviewed the process of analyzing SOER's as issued by WANO.

In chapter 2 an overview was given of the different international organizations which internationally help improve the safety and performance of the NPP's.

The importance of the SOER's for the industry was demonstrated and an overview of the different existing SOER's was given.

In chapter 3 the analyses of the SOER's which were already done by NPP Doel were reviewed in order to evaluate the analysis method and in order to come to an improved analysis method.

Several improvements were identified, such as:

- Each SOER must be given to one person who has the final responsibility for the timely and correct analysis of the SOER with all its recommendations. This responsibility and ownership includes the follow up of the actions defined upon completion.
- The support of the management of the power plant is important, in case the organisation does not give timely response to the questions of the analyzer.
- The researcher should preferably, but not mandatory, be the expert in the domain of the SOER.
- The researcher of the SOER shall be assisted by experts when necessary, in order to have the correct analysis.
- A final review and approval of the analysis by the management is mandatory, this will ensure quality and timeliness of the analysis.
- A periodic review of the SOER's is a good practice. This will ensure that due to for instance organisational changes, the recommendations are challenged with regard to the changing environment. This will also ensure that no new gaps are created.

In chapter 4 these improvements and analysis method were used to analyze the SOER 2007-1 regarding reactivity management. This gave rise to several actions that are necessary to be compliant with the recommendations mentioned in this SOER. These actions are currently in the process of implementation:

- Revise procedure EXPL/O/20 so that operation at very low power (<85%) is integrated
- Follow up on training regarding HU tools
- Revise procedure EXPL/O/07 to make this rule more concrete and communicate about the change
• Consider options to limit access to control room more strictly and implement
• Clarify role and responsibilities with regard to reactor engineer
• Revise the management expectations (with focus on reactivity management)
• Evaluate and adapt training program with regards to management expectations taking into consideration observations of gaps
• Repeat management expectations on a frequent basis so that they become second nature
• Establish an action plan to solve this long standing problems, and prioritize them according to impact on reactivity control
• Follow up of RCM project and encode equipment with impact on reactivity in SAP.

In order to have the possibility for a strict follow up by the management of Doel, I established a table with the SOER’s which needed a periodic review. For each SOER a responsible person was appointed with a coach from the management team. This improvement was implemented following this analysis, the WANO Peer review and follow up, and in anticipation of the OSART mission that the Doel power plant will receive beginning 2010.
BIBLIOGRAPHY

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[5] 1.G.02 for Unit Doel 1 (SAP reference 10000025863) : Start group from hot standby to 100%

[6] 2.G.02 for Unit Doel 2 (SAP reference 10000025861) : Start group from hot standby to 100%

[7] F-RE-01 for unit Doel 3 (SAP reference 10000022199) : Making the reactor critical

[8] F-RE-01 for unit Doel 4 (SAP reference 10000024710) : Making the reactor critical


[10] EXPL/O/20 : (SAP reference 10000750094) : Rules to be followed during operations at reduced power at NPP Doel

Appendix 1 – Chernobyl incident (26 April 1986)

A. Plant Description (See Figure 15)

Chernobyl 4, a Soviet RBMK-1000 type reactor, was rated at 3,200 MW thermal power and 1,000 MW electric output. The RBMK-1000 is a graphite moderated boiling water reactor that contains 1,661 parallel, vertical pressure tubes loaded with fuel assemblies. Reactor water flow is provided by six of eight installed main circulation pumps; two pumps are installed spares. Plant procedures place upper limits on the discharge flow of any of the pumps to avoid cavitation. The water-steam mixture leaving the top of the fuel channels flows into four horizontal steam drums with moisture separators. The dry steam drives two 500-MWe turbine generators (No. 7 and No. 8). Feedwater is fed directly to the steam drums, bypassing the reactor, to control water level. The reactor exhibits a reactivity increase as water density in the core decreases (positive void coefficient of reactivity). In normal operation, the overall power coefficient is negative at and near full power but becomes positive at lower power levels. The minimum permitted power level for steady-state operation is 700 MW(th) (22 percent of full power). Unless quickly restarted after a shutdown, startup is delayed due to xenon poisoning. Control and protection of the reactor is by movement of 211 boron carbide absorber rods in vertical channels adjacent to the fuel channels. The rods have graphite followers attached to displace water in the rod channels. The followers are not full core length, so when a rod is fully withdrawn from the core, about 1 meter of water remains in the rod channel below the follower. The time to fully insert rods for a scram is 20 seconds. A minimum operating reactivity margin is specified, equivalent to 30 inserted regulating rods, to ensure a certain initial negative reactivity rate on scram.
Figure 15 - Schematic diagram of RBMK - 1000 Chernobyl
B. Event Description

On April 25, 1986, at 01h00, the operators started reducing power to perform a test on turbine-generator No. 8, prior to a maintenance outage. The test was intended to determine how long the turbine-generator would continue to supply power near rated voltage for essential equipment as the generator coasted down.

At 13h05, turbine-generator No. 7 was shut down with the reactor at 50 percent power. Much of the electric power for the plant, including four main circulation pumps and two main feed pumps, was now being provided by turbine-generator No. 8.

At 14h00, the emergency core cooling system was defeated in accordance with the test program. Evidently this was to ensure that an inadvertent actuation would not interfere with the test. The test was then delayed nine hours due to a request from the load dispatcher to continue power generation. Operation of the plant at reduced power, using only turbine-generator No. 8, continued until 23h10 on April 25. At 23h10, the power reduction resumed. Accordingly to the test procedure, the coastdown of the generator was to be started with the reactor power at 700-1,000 MW(th). However, in switching the automatic control systems from spatial power control to power level control, the control point had not been properly set. As a result, the power fell below 30 MW(th).

At 01h00 on April 26, power was stabilized briefly at 200 MW(th). Xenon poisoning of the reactor continued to increase. To compensate, the operators withdrew additional rods (more than allowed by plant procedures). A further increase in power to 700-1,000 MW(th), as called for in the test procedure, was hampered by the small excess reactivity available.

At 01h03, two additional main circulation pumps were started, so that all eight were running. (Four pumps were powered by another source to provide for cooling of the reactor core, while the four circulation pumps powered by turbine-generator No. 8 would coast down as part of the test.) The coolant flow rate now exceeded the maximum allowed by operating procedures. The operators experienced difficulty in controlling steam drum pressure and water level. To avoid an automatic shutdown, the operators bypassed the emergency protection signals for reactor scrams on steam drum pressure and water level. Reactivity continued to drop due to xenon buildup, requiring further control rod withdrawal to maintain power at 200 MW(th).

At 01h22:30, the operators noted that the available reactivity margin, related to the number of rods and their positions in the core, had dropped well below the level requiring immediate
shutdown of the reactor. Nevertheless, the operators continued with the test. The operators also bypassed the reactor scram that would be initiated by the shutdown of the second turbine-generator (No. 8). This was done so it would be possible to repeat the test if the first attempt was unsuccessful.

At 01h23:04, the stop valves for turbine-generator No. 8 were closed, starting the coastdown test. The reactor was still critical and at power. As the circulation pumps coasted down, the lower flow allowed more steam to form in the core. Because of the strongly positive void coefficient, this initiated a power rise as the test began. The increased power further increased the steam voids. The regulating rods began inserting, but the power continued to rise.

On the supervisor's order, an operator pushed the reactor scram button at 01h23:40 to scram the shutdown rods, but these rods were near the top of the core and power continued to rise. A loud noise was heard from the reactor. The core reactivity exceeded prompt critical, and the power peak exceeded 100 times nominal full power.

Disintegration of the fuel stopped the chain reaction. A rapid increase in pressure resulted as fuel at very high temperatures contacted the water. The energy release lifted the 1,000-ton reactor cover plate, severing all the fuel channels. The refueling machine and its crane collapsed onto the reactor. Upper portions of the reactor building were destroyed. Hot segments from the core were ejected from the reactor, and the graphite in the reactor was ignited.

Approximately 30 localized fires started, involving roofing materials and other combustibles. This incident resulted in the release of about 50 million curies of particulate and iodine radioactivity, or about 3 to 4 percent of total core inventory. This resulted in evacuation of 135,000 people from the area within 30 kilometers of the plant, gross radioactive contamination of the plant site, contamination of other portions of the evacuated area, and distribution of measurable amounts of radioactivity over other countries.

Approximately 200 personnel were hospitalized from radiation exposure at the site, and 31 fatalities from this group have been reported to date.
Appendix 2 – Non Proliferation Treaty

TREATY ON THE NON-PROLIFERATION OF NUCLEAR WEAPONS

Notification of the entry into force

1. By letters addressed to the Director General on 5, 6 and 20 March 1970 respectively, the Governments of the United Kingdom of Great Britain and Northern Ireland, the United States of America and the Union of Soviet Socialist Republics, which are designated as the Depositary Governments in Article IX, 2 of the Treaty on the Non-Proliferation of Nuclear Weapons, informed the Agency that the Treaty had entered into force on 5 March 1970.

2. The text of the Treaty, taken from a certified true copy provided by one of the Depositary Governments, is reproduced below for the convenience of all Members.

TREATY

ON THE NON-PROLIFERATION OF NUCLEAR WEAPONS

The States concluding this Treaty, hereinafter referred to as the “Parties to the Treaty”,

Considering the devastation that would be visited upon all mankind by a nuclear war and the consequent need to make every effort to avert the danger of such a war and to take measures to safeguard the security of peoples,

Believing that the proliferation of nuclear weapons would seriously enhance the danger of nuclear war,

In conformity with resolutions of the United Nations General Assembly calling for the conclusion of an agreement on the prevention of wider dissemination of nuclear weapons,

Undertaking to co-operate in facilitating the application of International Atomic Energy Agency safeguards on peaceful nuclear activities,

Expressing their support for research, development and other efforts to further the application, within the framework of the International Atomic Energy Agency safeguards system, of the principle of safeguarding effectively the flow of source and special fissionable materials by use of instruments and other techniques at certain strategic points,

Affirming the principle that the benefits of peaceful applications of nuclear technology, including any technological by-products which may be derived by nuclear-weapon States from the development of nuclear explosive devices, should be available for peaceful purposes to all Parties to the Treaty, whether nuclear-weapon or non-nuclear-weapon States,

Convinced that, in furtherance of this principle, all Parties to the Treaty are entitled to participate in the fullest possible exchange of scientific information for, and to contribute alone or in co-operation with other States to, the further development of the applications of atomic energy for peaceful purposes,

Declaring their intention to achieve at the earliest possible date the cessation of the nuclear arms race and to undertake effective measures in the direction of nuclear disarmament,

Urging the co-operation of all States in the attainment of this objective.
Recalling the determination expressed by the Parties to the 1963 Treaty banning nuclear weapon tests in the atmosphere, in outer space and under water in its Preamble to seek to achieve the discontinuance of all test explosions of nuclear weapons for all time and to continue negotiations to this end,

Desiring to further the easing of international tension and the strengthening of trust between States in order to facilitate the cessation of the manufacture of nuclear weapons, the liquidation of all their existing stockpiles, and the elimination from national arsenals of nuclear weapons and the means of their delivery pursuant to a Treaty on general and complete disarmament under strict and effective international control,

Recalling that, in accordance with the Charter of the United Nations, States must refrain in their international relations from the threat or use of force against the territorial integrity or political independence of any State, or in any other manner inconsistent with the Purposes of the United Nations, and that the establishment and maintenance of international peace and security are to be promoted with the least diversion for armaments of the world's human and economic resources,

Have agreed as follows:

ARTICLE I

Each nuclear-weapon State Party to the Treaty undertakes not to transfer to any recipient whatsoever nuclear weapons or other nuclear explosive devices or control over such weapons or explosive devices directly, or indirectly; and not in any way to assist, encourage, or induce any non-nuclear-weapon State to manufacture or otherwise acquire nuclear weapons or other nuclear explosive devices.

ARTICLE II

Each non-nuclear-weapon State Party to the Treaty undertakes not to receive the transfer from any transferor whatsoever of nuclear weapons or other nuclear explosive devices or of control over such weapons or explosive devices directly, or indirectly; nor to manufacture or otherwise acquire nuclear weapons or other nuclear explosive devices, and not to seek or receive any assistance in the manufacture of nuclear weapons or other nuclear explosive devices.

ARTICLE III

1. Each Non-nuclear-weapon State Party to the Treaty undertakes to accept safeguards, as set forth in an agreement to be negotiated and concluded with the International Atomic Energy Agency in accordance with the Statute of the International Atomic Energy Agency and the Agency's safeguards system, for the exclusive purpose of verification of the fulfilment of its obligations assumed under this Treaty with a view to preventing diversion of nuclear energy from peaceful uses to nuclear weapons or other nuclear explosive devices. Procedures for the safeguards required by this Article shall be followed with respect to source or special fissile material whether it is being produced, processed or used in any principal nuclear facility or is outside any such facility. The safeguards required by this Article shall be applied on all source or special fissile material in all peaceful nuclear activities within the territory of such State, under its jurisdiction, or carried out under its control anywhere.
2. Each State Party to the Treaty undertakes not to provide: (a) source or special fissionable material, or (b) equipment or material especially designed or prepared for the processing, use or production of special fissionable material, to any non-nuclear-weapon State for peaceful purposes, unless the source or special fissionable material shall be subject to the safeguards required by this Article.

3. The safeguards required by this Article shall be implemented in a manner designed to comply with Article IV of this Treaty, and to avoid hampering the economic or technological development of the Parties or international co-operation in the field of peaceful nuclear activities, including the international exchange of nuclear material and equipment for the processing, use or production of nuclear material for peaceful purposes in accordance with the provisions of this Article and the principle of safeguarding set forth in the Preamble of the Treaty.

4. Non-nuclear-weapon States Party to the Treaty shall conclude agreements with the International Atomic Energy Agency to meet the requirements of this Article either individually or together with other States in accordance with the Statute of the International Atomic Energy Agency. Negotiation of such agreements shall commence within 180 days from the original entry into force of this Treaty. For States depositing their instruments of ratification or accession after the 180-day period, negotiation of such agreements shall commence not later than the date of such deposit. Such agreements shall enter into force not later than eighteen months after the date of initiation of negotiations.

ARTICLE IV

1. Nothing in this Treaty shall be interpreted as affecting the inalienable right of all the Parties to the Treaty to develop research, production and use of nuclear energy for peaceful purposes without discrimination and in conformity with Articles I and II of this Treaty.

2. All the Parties to the Treaty undertake to facilitate, and have the right to participate in, the fullest possible exchange of equipment, materials and scientific and technological information for the peaceful uses of nuclear energy. Parties to the Treaty in a position to do so shall also cooperate in contributing alone or together with other States or international organizations to the further development of the applications of nuclear energy for peaceful purposes, especially in the territories of non-nuclear-weapon States Party to the Treaty, with due consideration for the needs of the developing areas of the world.

ARTICLE V

Each Party to the Treaty undertakes to take appropriate measures to ensure that, in accordance with this Treaty, under appropriate international observation and through appropriate international procedures, potential benefits from any peaceful applications of nuclear explosions will be made available to non-nuclear-weapon States Party to the Treaty on a non-discriminatory basis and that the charge to such Parties for the explosive devices used will be as low as possible and exclude any charge for research and development. Non-nuclear-weapon States Party to the Treaty shall be able to obtain such benefits, pursuant to a special international agreement or agreements, through an appropriate international body with adequate representation of non-nuclear-weapon States. Negotiations on this subject shall commence as soon as possible after the Treaty enters into force. Non-nuclear-weapon States Party to the Treaty so desiring may also obtain such benefits pursuant to bilateral agreements.
ARTICLE VI

Each of the Parties to the Treaty undertakes to pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament, and on a treaty on general and complete disarmament under strict and effective international control.

ARTICLE VII

Nothing in this Treaty affects the right of any group of States to conclude regional treaties in order to assure the total absence of nuclear weapons in their respective territories.

ARTICLE VIII

1. Any Party to the Treaty may propose amendments to this Treaty. The text of any proposed amendment shall be submitted to the Depositary Governments which shall circulate it to all Parties to the Treaty. Thereupon, if requested to do so by one-third or more of the Parties to the Treaty, the Depositary Governments shall convene a conference, to which they shall invite all the Parties to the Treaty, to consider such an amendment.

2. Any amendment to this Treaty must be approved by a majority of the votes of all the Parties to the Treaty, including the votes of all nuclear-weapon States Party to the Treaty and all other Parties which, on the date the amendment is circulated, are members of the Board of Governors of the International Atomic Energy Agency. The amendment shall enter into force for each Party that deposits its instrument of ratification of the amendment upon the deposit of such instruments of ratification by a majority of all the Parties, including the instruments of ratification of all nuclear-weapon States Party to the Treaty and all other Parties which, on the date the amendment is circulated, are members of the Board of Governors of the International Atomic Energy Agency. Thereafter, it shall enter into force for any other Party upon the deposit of its instrument of ratification of the amendment.

3. Five years after the entry into force of this Treaty, a conference of Parties to the Treaty shall be held in Geneva, Switzerland, in order to review the operation of this Treaty with a view to assuring that the purposes of the Preamble and the provisions of the Treaty are being realised. At intervals of five years thereafter, a majority of the Parties to the Treaty may obtain, by submitting a proposal to this effect to the Depositary Governments, the convening of further conferences with the same objective of reviewing the operation of the Treaty.

ARTICLE IX

1. This Treaty shall be open to all States for signature. Any State which does not sign the Treaty before its entry into force in accordance with paragraph 3 of this Article may accede to it at any time.

2. This Treaty shall be subject to ratification by signatory States. Instruments of ratification and instruments of accession shall be deposited with the Governments of the United Kingdom of Great Britain and Northern Ireland, the Union of Soviet Socialist Republics and the United States of America, which are hereby designated the Depositary Governments.

3. This Treaty shall enter into force after its ratification by the States, the Governments of which are designated Depositaries of the Treaty, and forty other States signatory to this Treaty and the deposit of their instruments of ratification. For the purposes of this Treaty, a nuclear-weapon State is one which has manufactured and exploded a nuclear weapon or other nuclear explosive device prior to 1 January, 1967.
4. For States whose instruments of ratification or accession are deposited subsequent to the entry into force of this Treaty, it shall enter into force on the date of the deposit of their instruments of ratification or accession.

5. The Depositary Governments shall promptly inform all signatory and acceding States of the date of each signature, the date of deposit of each instrument of ratification or of accession, the date of the entry into force of this Treaty, and the date of receipt of any requests for convening a conference or other notices.

6. This Treaty shall be registered by the Depositary Governments pursuant to Article 102 of the Charter of the United Nations.

ARTICLE X

1. Each Party shall in exercising its national sovereignty have the right to withdraw from the Treaty if it decides that extraordinary events, related to the subject matter of this Treaty, have jeopardized the supreme interests of its country. It shall give notice of such withdrawal to all other Parties to the Treaty and to the United Nations Security Council three months in advance. Such notice shall include a statement of the extraordinary events it regards as having jeopardized its supreme interests.

2. Twenty-five years after the entry into force of the Treaty, a conference shall be convened to decide whether the Treaty shall continue in force indefinitely, or shall be extended for an additional fixed period or periods. This decision shall be taken by a majority of the Parties to the Treaty.

ARTICLE XI

This Treaty, the English, Russian, French, Spanish and Chinese texts of which are equally authentic, shall be deposited in the archives of the Depositary Governments. Duly certified copies of this Treaty shall be transmitted by the Depositary Governments to the Governments of the signatory and acceding States.

IN WITNESS WHEREOF the undersigned, duly authorised, have signed this Treaty.

DONE in triplicate, at the cities of London, Moscow and Washington, the first day of July, one thousand nine hundred and sixty-eight.
Appendix 3 – Three Mile Island incident

Three Mile Island, Unit 2, utilized a Babcock & Wilcox supplied pressurized water reactor rated at 880 MW net electrical. The reactor had attained initial criticality on March 28, 1978, and at the time of the accident, was operating on its first fuel loading. The core, containing approximately 100 tons of UO$_2$ in 37,000 fuel rods, had reached an average burn-up of 3175 MWD/ton.

![Figure 16 - Schematic of Three Mile Island NPP](image)

- Primary System (Figure 17)
  
  In each of the two primary coolant loops, flow was provided by two pumps, and heat was extracted through a vertical steam generator capable of providing superheated steam. The inventory of feedwater in the steam generator would be completely depleted in approximately
A pressurizer connected to primary loop A maintained primary system pressure at 2150 psig and provided surge volume to accommodate expansion and contraction of the primary system water. Pressure was controlled with electric heaters and with a cooling water spray coming from the pump discharge in one of the primary coolant loops. The normal operating water level in the pressurizer was about 220 inches. A power-operated relief valve, with a capacity of 100,000 pounds per hour of saturated steam, would open at 2255 psig, discharging to the reactor coolant drain tank. A block valve, upstream of the relief valve, could be remotely closed manually in the event the relief valve stuck open or leaked. The relief valve typically opened during some plant transients (for example, loss of load or loss of main feedwater).

An indicator light installed on the control room panel came on when the valve was signaled to open and went out when the signal was removed.

Figure 17 - Primary system of Three Mile Island
Feedwater Systems (Figure 18)

Condensate from the condenser was pumped by condensate pumps through the full flow condensate polishers, eight resin beds in parallel. The resin was periodically removed for regeneration using water and air from the plant air service supply, which was interconnected to the instrument air supply. A motor-operated valve bypassing the polisher could be opened manually from the control room in the event the polisher needed to be bypassed. The polishers would not normally be bypassed, even when out of service for resin regeneration. This bypass valve was not easily accessible for local manual operation. The condensate pressure was raised by condensate booster pumps, and the temperature was raised in low pressure feedwater heaters. The water was then pumped by feedwater pumps through high pressure feedwater heaters to the once-through steam generators.

Three emergency, auxiliary feedwater pumps (two electric, one steam driven) would start automatically on loss of the main feedwater pumps to directly feed the steam generators. In the line to each steam generator were an automatic control valve and a manual block valve.
**Figure 18 - Three Mile Island feedwater system**

- **Integrated Control System**

  The integrated control system automatically coordinated the action of plant equipment to match power generated to power demand. Its functions included the control of steam header pressure, control rod positioning, feedwater flow, and steam bypass valve position. On a turbine trip, the integrated control system automatically reduced reactor power by inserting control rods. With no other casualty, the plant was designed to accommodate a turbine trip without a reactor scram.

- **High Pressure Injection, Makeup, and Letdown System**

  During normal operation, water was let down from the reactor coolant systems, near the suction of reactor coolant pump RCP-1A. The water removed was purified and cooled and sent either to the reactor coolant bleed tanks or the makeup tank. At least one of the three high pressure makeup pumps always operated, supplying water to the reactor coolant pump.
seals. Any additional water required to maintain the correct inventory in the reactor coolant system was regulated by valve MU-V17, which was controlled by pressurizer level; the water entered the discharge line of coolant pump RCP-1B.

In the high pressure injection mode (when the engineered safeguards were actuated), two makeup pumps, normally 1A and 1C, took water directly from the borated water storage tank and pumped through valve MU-V16A, 16B, 16C, and 16D to all four reactor coolant system cold legs. Each of the three makeup pumps had a capacity of approximately 300 gallons per minute at a design head of 2400 psig. Letdown flow, normally 45 to 70 gallons per minute, was automatically stopped during engineered safeguards operation.

- Gas Venting System

Gases, normally nitrogen cover gas, vented from waste storage tanks and from other vents, were piped to the waste gas vent header. Gas was pumped from the header to the waste gas decay tanks by the waste gas compressors. The gas was held in the decay tanks to allow partial decay of the radioactivity and was finally discharged to the atmosphere through the station vent chimney after being filtered in the waste gas filters.

- The Accident

At 4:00 a.m., March 28, 1979, the feedwater systems at Three Mile Island, Unit 2, tripped offline while the reactor was operating at full power. The main turbine tripped, but the auxiliary feedwater system failed to deliver water. The power-operated relief valve (PORV) opened, and the reactor scrammed. The PORV failed to close when the primary pressure decreased, resulting in a continuous loss of coolant for 2½ hours.

High pressure injection, which initiated automatically, was throttled back. Pressurizer function was lost, and steam formed in the reactor. When the reactor coolant pumps were stopped and the PORV was blocked, all effective cooling of the core ceased. The core overheated, zircaloy cladding reacted with steam forming a hydrogen bubble, and fuel melted.
Appendix 4 – List of current WANO members

Currently the following companies are member of WANO:

<table>
<thead>
<tr>
<th>Country/Area</th>
<th>WANO Ordinary Member</th>
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<tbody>
<tr>
<td>Argentina</td>
<td>Nucleoelectrica Argentina SA</td>
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<tr>
<td>Armenia</td>
<td>Armenian Nuclear Power Plant Ltd Co</td>
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<tr>
<td>Belgium</td>
<td>Electrabel</td>
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<td>Brazil</td>
<td>Eletrobrás Termonuclear SA</td>
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<td>Bulgaria</td>
<td>Kozloduy NPP Plc</td>
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<tr>
<td>Canada</td>
<td>CANDU Operators Group</td>
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<td>China</td>
<td>China National Nuclear Corporation</td>
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<tr>
<td>Cuba</td>
<td>Ministry of Industries</td>
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<tr>
<td>Czech Republic</td>
<td>CEZ Inc. Nuclear Division</td>
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<tr>
<td>Finland</td>
<td>Finnish WANO Members Group</td>
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<tr>
<td>France</td>
<td>Electricité de France</td>
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<td>Germany</td>
<td>VGB Power Tech e.V.</td>
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<td>Hungary</td>
<td>Paks Nuclear Power Plant Ltd</td>
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<td>India</td>
<td>Nuclear Power Corporation of India Ltd</td>
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<td>Japanese Nuclear Operators</td>
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<td>Lithuania</td>
<td>Ignalina Nuclear Power Plant</td>
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<td>Mexico</td>
<td>Comisión Federal de Electricidad</td>
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<td>NV Elektriciteits-Produktiemaatschappij Zuid-Nederland</td>
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<td>Pakistan</td>
<td>Pakistan Atomic Energy Commission</td>
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<td>Poland</td>
<td>Institute of Atomic Energy</td>
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<td>Country</td>
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<tr>
<td>Romania</td>
<td>Societatea Nationala &quot;Nuclearelectrica&quot; SA</td>
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<tr>
<td>Russia</td>
<td>Concern Rosenergoatom</td>
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<td>Slovak Republic</td>
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<td>BNFL Magnox Generation</td>
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<td>United States</td>
<td>Institute of Nuclear Power Operations</td>
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Appendix 5 – WANO Performance Indicators

WANO monitors five additional performance indicators: safety system performance, fuel reliability, chemistry performance, grid-related loss factor and contractor industrial safety accident rate. The first three indicators are defined in a manner that reflects differences in plant-specific designs, configurations, or operational practices. As a result, data can not be summarized across reactor types for inclusion in this report. The last two are new indicators. These indicators are available to WANO members in more detailed reports on the WANO Website.

Safety System Performance
The safety system performance indicator monitors the availability of three important standby safety systems at each plant. Safety systems that are maintained in a high state of readiness have a high probability of being capable of mitigating off-normal events.

Chemistry Performance
The chemistry performance indicator provides an indication of progress in controlling chemical parameters to retard deterioration of key plant materials and components. These parameters are already being maintained within strict guidance developed by the industry.

Grid-Related Loss Factor
The grid-related loss factor is the percentage of maximum energy generation that a plant could not supply due to grid issues not under plant management control.

Contractor Industrial Safety Accident Rate
The contractor industrial safety accident rate tracks the number of accidents among contractors that result in lost work time, restricted work, or fatalities per 200,000 work-hours.

The WANO Performance Indicator Programme supports the exchange of operating experience information by collecting, trending and disseminating nuclear plant performance data in 11 key areas. The data is gathered for a set of quantitative indicators of plant performance. These indicators are intended principally for use as a management tool by nuclear operating organisations to monitor their own performance and progress, to set their own challenging goals for improvement, and to gain additional perspective on performance relative to that of other plants.

It is now widely recognised that a good set of overall performance indicators can provide a partial, but important and useful, measure of how well a nuclear plant is managed overall.

WANO published and distributed the first performance indicator report in April 1991. In 1993, reporting of data began for all reactor designs. Currently, 72 percent of the operating nuclear power plants report all eleven indicators.

It is expected that the use of WANO performance indicators will encourage emulation of the best industry performance. It should also further motivate the identification and exchange of good practices in nuclear plant operations.

Notes:
(1) The median of plant values is displayed for all indicators except unplanned automatic scrams per 7,000 hours critical, where the mean of plant values is shown, and industrial safety accident rate, which is an overall industry value (summarized of plant values).

(2) Half of the plant values are above and half are below the displayed median values. The mean is the arithmetical average of the plant values. The median value is normally displayed rather than the mean value because the median value is less susceptible to influence of outliers and is therefore more representative of overall performance.

(3) Worldwide collection of data needed to calculate the forced loss rate indicator did not begin until 2001.
Unit Capability Factor

Unit capability factor is the percentage of maximum energy generation that a plant is capable of supplying to the electrical grid, limited only by factors within control of plant management. A high unit capability factor indicates effective plant programmes and practices to minimise unplanned energy losses and to optimise planned outages.

Unplanned Capability Loss Factor

The unplanned capability loss factor is the percentage of maximum energy generation that a plant is not capable of supplying to the electrical grid because of unplanned energy losses, such as unplanned shutdowns or outage extensions. A low value indicates important plant equipment is well maintained and reliably operated and there are few outage extensions.

Forced Loss Rate

The forced loss rate is the percentage of energy generation during non-outage periods that a plant is not capable of supplying to the electrical grid because of unplanned energy losses, such as unplanned shutdown or load reductions. A low value indicates important plant equipment is well maintained and reliably operated. (See Note 3.)
Collective Radiation Exposure

The collective radiation exposure indicator monitors the effectiveness of personnel radiation exposure controls for boiling water reactors (BWRs), pressurised water reactors (PWRs), pressurised heavy water reactors (PHWRs), light-water-cooled graphite reactors (LWCGRs), and gas-cooled reactors (GCRs). Low exposure indicates strong management attention to radiological protection.
Unplanned Automatic Scrams per 7,000 Hours Critical

The unplanned automatic scrams per 7,000 hours critical indicator tracks the mean scram (automatic shutdown) rate for approximately one year (7,000 hours) of operation. Unplanned automatic scrams result in thermal and hydraulic transients that affect plant systems.

Industrial Safety Accident Rate

The industrial safety accident rate tracks the number of accidents among employees that result in lost work time, restricted work, or fatalities per 200,000 work-hours. The nuclear industry continues to provide one of the safest industrial work environments.
Appendix 6 – INSAG 19

The International Nuclear Safety Group (INSAG) is a group of experts with high professional competence in the field of safety working in regulatory organizations, research and academic institutions and the nuclear industry. INSAG is convened under the auspices of the International Atomic Energy Agency (IAEA) with the objective to provide authoritative advice and guidance on nuclear safety approaches, policies and principles. In particular, INSAG will provide recommendations and opinions on current and emerging nuclear safety issues to the IAEA, the nuclear community and the public.

The INSAG 19 is the 19th document published by the INSAG and talks about the role of design authority in the nuclear power plants. Each nuclear power plant has received an operating licence based on their initial design upon construction. However in the course of time, changes to the power plant will occur, which will affect the original design of the power plant. It is the responsibility of the design authority to make sure that no changes are made to the design which have a negative effect on the safety systems of the power plant.

More information regarding INSAG can be found on the following website: http://www-ns.iaea.org/committees/insag.asp
Appendix 7 – Overview of different types of nuclear power reactors

1. Pressurised Water Reactor (PWR)

In a typical commercial pressurized light-water reactor (1) the reactor core generates heat, (2) pressurized-water in the primary coolant loop carries the heat to the steam generator, (3) inside the steam generator heat from the primary coolant loop vaporizes the water in a secondary loop producing steam, (4) the steam line directs the steam to the main turbine causing it to turn the turbine generator, which produces electricity. The unused steam is exhausted to the condenser where it is condensed into water. The resulting water is pumped out of the condenser with a series of pumps, reheated, and pumped back to the steam generator. The reactors core contains fuel assemblies which are cooled by water, which is force-circulated by electrically powered pumps. Emergency cooling water is supplied by other pumps, which can be powered by onsite diesel generators. Other safety systems, such as the containment cooling system, also need power.
2. Boiling Water Reactor (BWR)

In a typical commercial boiling water reactor (1) the reactor core creates heat, (2) a steam-water mixture is produced when very pure water (reactor coolant) moves upward through the core absorbing heat, (3) the steam-water mixture leaves the top of the core and enters the two stages of moisture separation where water droplets are removed before the steam is allowed to enter the steam line, (4) the steam line directs the steam to the main turbine causing it to turn the turbine generator, which produces electricity. The unused steam is exhausted to the condenser where it is condensed into water. The resulting water is pumped out of the condenser with a series of pumps, reheated, and pumped back to the reactor vessel. The reactor's core contains fuel assemblies which are cooled by water, which is force-circulated by electrically powered pumps. Emergency cooling water is supplied by other pumps which can be powered by onsite diesel generators. Other safety systems, such as the containment cooling system, also need electric power.

Figure 20 - Schematic of BWR
3. VVER

VVER is the Soviet (and now, Russian Federation) designation for light water pressurized reactor. In western countries, the PWR is used as the acronym. For the general public, the perception may be that all Soviet-designed reactors are identical to (or at least similar to) the reactors at Chernobyl. The Chernobyl reactor, however, is a light-water cooled, graphite-moderated reactor (LWCGR). It is considered by many experts to be a flawed design that is vulnerable to fire. Around the time LWCGRs were coming on line in the Soviet Union, early VVERs were also coming on line, many with safety innovations based on western designs.

The international community has encouraged the shutdown of various LWCGRs, but the need for electric power and the employment the power plants provide have made this a lengthy process. After unit 4 was destroyed by fire at Chernobyl, the other 3 units were returned to service and one continued to operate into the 21st century. Recently, Lithuania agreed to shut down its two LWCGR units at Ignalina. The units provide nearly 80 percent of the country’s electricity, making this a very difficult economic decision.

The Russian Federation continues to build VVER units. While any Russian-built unit may suffer from the image of the disaster to Chernobyl 4, the new units conform to international standards and have developed an export market.

4. Gas Cooled Reactor (GCR)

The Gas Cooled Reactor was one of the original designs. In the Gas Cooled Reactor (GCR), the moderator is graphite. Inert gas, e.g. helium or carbon dioxide, is used as the coolant. The advantage of the design is that the coolant can be heated to higher temperatures than water. As a result, higher plant efficiency (40% or more) could be obtained compared to the water cooled design (33-34%).

In the United States, Gulf General Atomics was the proponent of this design. Public Service of Colorado (now Xcel Energy) built the Fort Saint Vrain facility north of Denver. A short history describes the trials and tribulations experienced during the 1968 - 1995 period of construction, startup, operation, shutdown, and decommissioning of the nuclear section of the facility. The NRC has also written NUREG/CR-6839, Fort Saint Vrain Gas Cooled Reactor Operational Experience. Currently, there is little movement toward the gas cooled design in the US or elsewhere.
In the United Kingdom, the government was the proponent that developed, constructed, and operated a number of gas cooled reactors. The older design used carbon dioxide gas circulating through the core at a pressure of ~1.6 MPa or 230 pounds per square inch to remove the heat from the fuel elements. The fuel consists of natural uranium metal clad with an alloy of magnesium known as Magnox (thus the name for the reactor type).

The newer Advanced Gas Cooled (AGR) Reactors use a slightly enriched uranium dioxide clad with stainless steel. Carbon dioxide is the coolant gas used.

Two key advantages of this design are:

- higher operating temperature with a higher thermal efficiency
- not susceptible to accidents of the type possible with water cooled/moderated reactors.

The Gas Cooled Reactor or Advanced Gas Reactor cycle is illustrated in the simple sketch below:

![Advanced gas cooled reactor](image)

5. Pressurized Heavy Water Reactor (PHWR)

The CANDU reactor design has been developed since the 1950s in Canada. It uses natural uranium (0.7% U-235) oxide as fuel, hence needs a more efficient moderator, in this case heavy water (D₂O). (with the CANDU system, the moderator is enriched (ie water) rather than the fuel, - a cost trade-off.)

The moderator is in a large tank called a calandria, penetrated by several hundred horizontal pressure tubes which form channels for the fuel, cooled by a flow of heavy water under high pressure.
pressure in the primary cooling circuit, reaching 290°C. As in the PWR, the primary coolant generates steam in a secondary circuit to drive the turbines. The pressure tube design means that the reactor can be refuelled progressively without shutting down, by isolating individual pressure tubes from the cooling circuit.

Figure 22 - Schematic of CANDU

A CANDU fuel assembly consists of a bundle of 37 half metre long fuel rods (ceramic fuel pellets in zircaloy tubes) plus a support structure, with 12 bundles lying end to end in a fuel channel. Control rods penetrate the calandria vertically, and a secondary shutdown system involves adding gadolinium to the moderator. The heavy water moderator circulating through the body of the calandria vessel also yields some heat (though this circuit is not shown on the diagram above).