IAEA-TECDOC-1402

Management of life cycle and ageing at nuclear power plants: Improved I&C maintenance

Report prepared within the framework of the Technical Working Group on Nuclear Power Plant Control and Instrumentation

IAEA
International Atomic Energy Agency

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The originating Section of this publication in the IAEA was:

Nuclear Power Engineering Section
International Atomic Energy Agency
Wagramer Strasse 5
P.O. Box 100
A-1400 Vienna, Austria

MANAGEMENT OF LIFE CYCLE AND AGEING AT NUCLEAR POWER PLANTS:
IMPROVED I&C MAINTENANCE
IAEA, VIENNA, 2004
IAEA-TECDOC-1402
ISBN 92–0–108804–3
ISSN 1011–4289

Printed by the IAEA in Austria
August 2004

FOREWORD

The topic of this TECDOC was originally suggested in the May 2001 meeting of the IAEA Technical Working Group on Nuclear Power Plant Control and Instrumentation (TWG NPP-CI). It was then approved by the IAEA for work to begin in 2002.

It originated from the remarks of the TWG members that it is now time to address the instrumentation and control (I&C) ageing issues in terms of plant life management and licence renewal. Furthermore, the nuclear industry is believed to be able to survive only if plant economy is favourable in addition to plant safety. Therefore, in dealing with I&C ageing and obsolescence, one has to consider how to proceed in addressing this question, not only from a plant operational and safety standpoint, but also in the context of plant economy in terms of the cost of electricity production, and including initial and recurring capital costs. For this important reason, consideration of new technologies, such as on-line monitoring and in situ testing methods is recommended. These can be used not only to predict the consequences of ageing, and guard against it, but also to verify equipment performance throughout the lifetime of the plant, and help establish replacement schedules for I&C equipment, and predict residual life.

The basic ageing and obsolescence management process involves:

- Understanding the ageing and obsolescence phenomena and identifying the (potential) effects on I&C;
- Addressing the specific impact of these effects on the plant taking into account operational profiles and analyzing the risks;
- Carrying out necessary mitigating actions to counteract the effects of ageing and obsolescence.

Based on the above listed activities the ageing and obsolescence management programme needs to be an iterative process.

The goal of this TECDOC is to provide the latest information on ageing, obsolescence, and performance monitoring of those I&C equipment that are classified as safety equipment and/or safety-related equipment, are operated in harsh environments in NPPs, and important in plant life management, not only for normal operation but also, and more importantly, for post-accident service. In reaching this goal, this TECDOC identifies the key I&C components of interest that are expected to function well throughout the life of a plant including the extended life. This TECDOC discusses the effects of ageing and obsolescence of this equipment, and describes state of the art techniques and new procedures that can be implemented remotely, while the plant is on-line, to verify the performance, adequacy, and availability. This TECDOC follows an earlier one (IAEA-TECDOC-1147) that was published on related subjects in June 2000.

This TECDOC was prepared by a group of experts from France, Hungary, the Republic of Korea, Switzerland, and the United States of America. Advisors from Canada, Germany, Japan, and the Russian Federation assisted in its publication.

The IAEA wishes to thank all participants and their Member States for their valuable contributions. The IAEA officers responsible for this publication were Ki-Sig Kang and J. Eiler of the Division of Nuclear Power.

CONTENTS

1. INTRODUCTION

1.1. OBJECTIVES

Although instrumentation and control (I&C) modernization projects have been implemented in a number of nuclear power plants (NPPs) over the last ten years, a majority of NPPs in the world still have most of their original and aged analogue I&C systems together with aged computer systems mainly supporting process information for plant operation. Major drivers for the modernization of I&C systems are the need for more cost effective power production, smooth operation, improved competitiveness, and for replacing of obsolete equipment. In addition, operating plants may occasionally need to modernize their I&C equipment to satisfy current extended requirements, as well as to meet the up to date national and international codes and standards.

As NPPs receive license renewal and look forward to decades of continuing operation, they will inevitably replace their aged and obsolete I&C systems. However, for most NPPs, these replacements will be phased in over several years, and careful planning and maintenance of ageing equipment will be needed in the meantime.

This TECDOC will use the existing body of information and knowledge from the worldwide nuclear power industry to build a case for the role of I&C in plant performance improvements in terms of both plant safety and plant economy. It will then provide recommendations as to what can be done to prevent I&C ageing and obsolescence from affecting the safe and economical performance of NPPs.

1.2. BACKGROUND

The world fleet of NPPs is approximately 20 years old on average (Fig. 1.1), and most plants are believed to be able to operate for 60 years or more. The design life of a NPP is typically 30 to 40 years. This may be extended by 10 to 20 years provided that the plant can demonstrate by analysis, trending, equipment and system upgrades, increased vigilance, testing, ageing management, and other means that license renewal is not a threat to the public health and safety.

This information makes it clear that it is now time to address the I&C ageing issues in terms of plant life management and license renewal. Furthermore, the nuclear industry is believed to be able to survive only if plant economy is favourable in addition to plant safety. Therefore, in dealing with I&C ageing and obsolescence, one has to consider how to proceed to address this question not only from a plant operational and safety standpoint, but also in the context of plant economy in terms of the cost of electricity production, including initial and recurring capital costs. For this important reason, it is recommended that one consider new technologies such as on-line monitoring and in-situ testing methods, as described in (IAEA-TECDOC-1147) [2] and mentioned in various chapters of this TECDOC, that can be used not only to predict the consequences of ageing, and guard against it, but also to verify equipment performance throughout the life of the plant, and to help establish replacement schedules for I&C equipment and to predict residual life.

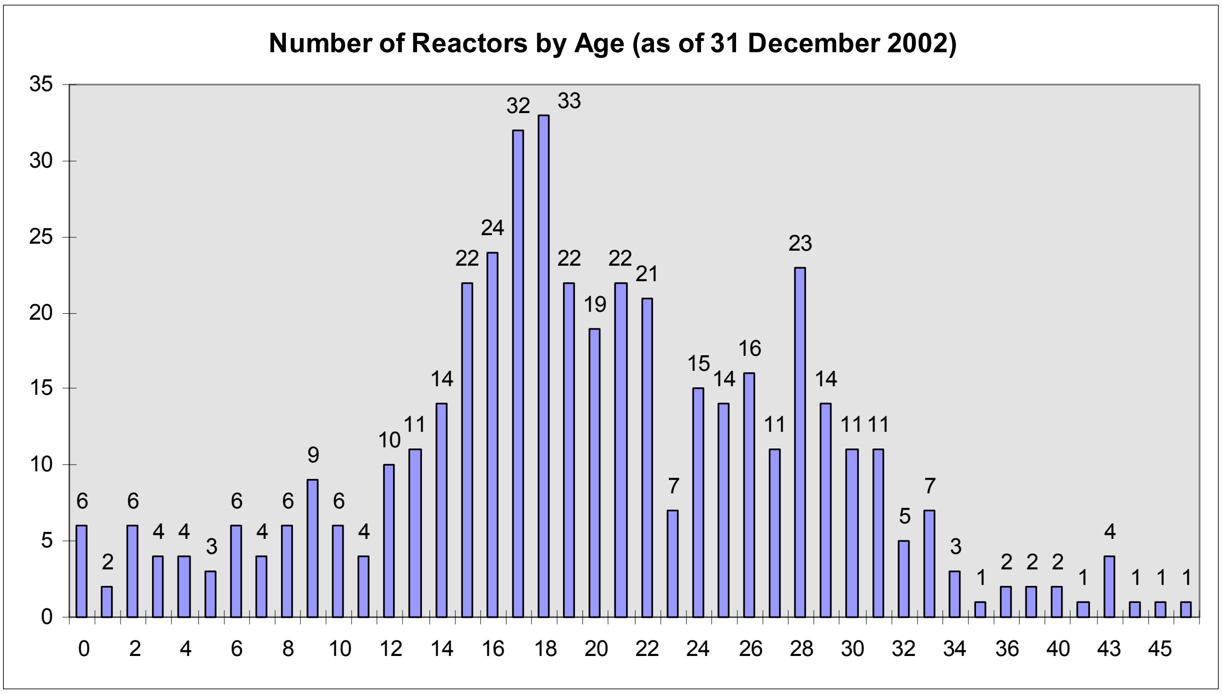

FIG. 1.1. Worldwide Population of NPPs by Age from Start of Operation.

1.3. EXAMPLES OF LONG TERM OPERATION ACTIVITIES

The Calvert Cliffs nuclear power station in the USA, and the Novovoronezh Units 3 and 4 in The Russian Federation were among the first plants to receive approval to operate up to 20 years (15 years for Novovoronezh) beyond their original licenses.

The licensing renewal process for the Calvert Cliffs plant was not very complicated and encouraged other plants in the USA, such as the Oconee nuclear station, Arkansas Nuclear One, and others to follow suit. As of July 2004, twenty-six nuclear plant units have successfully and rather easily obtained license renewal without major stipulations other than what is reasonably expected for the plant to ensure continued safety. In fact almost all U.S. plants have plans to apply for life extension, and the NRC licensing renewal processes are being further streamlined to accommodate the nuclear power industry. This is in contrast to only about ten years ago when plants were focused more on dismantling and decommissioning than life extension.

The renaissance of the nuclear power industry in the USA is giving rise to long term operation in other countries. There are also countries, such as Germany and Belgium, which plan to phase out nuclear power, but new events, such as Finland's decision to build a new NPP, and continued construction activities in China, Republic of Korea, Russian Federation, and other countries, are adding to the wisdom that new construction and long term operation may soon get underway, not only in the USA, but also in Europe and elsewhere. A lot of these new constructions will take advantage of advanced reactor designs. Also, modular plants, such as the Pebble Bed Reactor that has been developed in South Africa are being considered for construction. Most of the advanced reactor designs have received regulatory approval in their country of origin and are ready for deployment, and some advanced reactors have already been built such as the Kashiwazaki Kariwa units in Japan. In addition to advanced reactors and modular plants that are expected to meet the needs of this and the next decade, a number of Member States are working together today to design a new generation of NPPs to be deployed by 2030. Referred to as Generation Four (Gen IV) reactors, these new plants will be designed to be inherently safe, proliferation resistant, and more economical to build and operate.

1.4. COMPONENT CLASSIFICATION

Previous work has identified the structures, systems, and components (SSCs) of NPPs that are vulnerable to ageing [1, 2]. Here we have distributed the SSCs to those that are replaceable during the life of the plant and those that are not replaceable (see Fig. 1.2).

The I&C equipment are replaceable with various degrees of difficulty. For example, a Resistance Temperature Detector (RTD) that is installed in a thermowell in the primary coolant system of a pressurized water reactor (PWR) is easily replaced while I&C cables are not as easily replaced, although some plants have successfully managed these changes too. In either case, ageing is of concern not only for non-replaceable SSCs but also for replaceable SSCs such as the I&C equipment that are identified in Fig. 1.2. Although replacement is an option for ageing management of most I&C equipment, improved testing and on-line monitoring that is performed on a regular basis are viable alternatives and sometimes more prudent than replacing an I&C component.

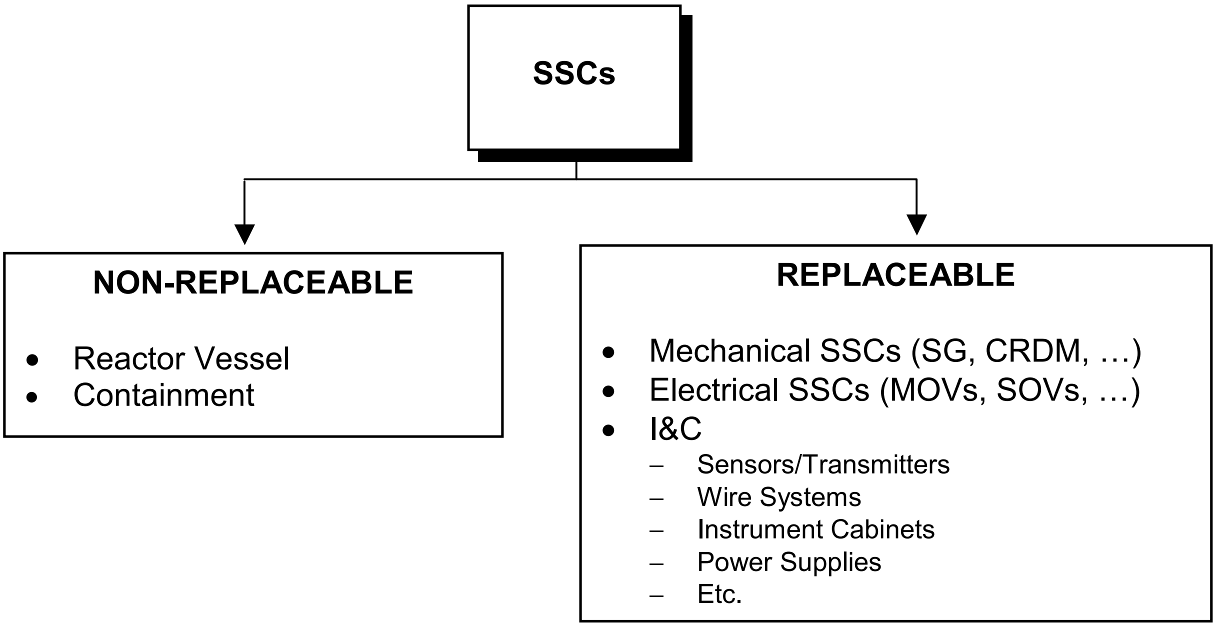

FIG. 1.2. Examples of Replaceable and Non-Replaceable SSCs.

This TECDOC is concerned only with I&C equipment that are referred to as safety equipment (e.g., Class 1E), as well as those I&C equipment that are related to safety and are referred to as safety-related equipment. Other I&C equipment that do not have a specific safety function are not of main concern in this report, although the strategies and testing methods that are outlined in this TECDOC would be useful also for other I&C equipment.

To clarify the safety ranking of the I&C equipment, Fig. 1.3 is included here from an earlier TECDOC report [3] to show what is meant here by Class 1E, and others, as classification protocols are not the same in different Member States.

ORGANIZATIONS AND/OR COUNTRIES	CLASSIFICATION			
IAEA	Systems Important to Safety		Systems not important to safety	
	Safety system	Safety related system		
IEC	Category A	Category B	Category C	Unclassified
France	1E	2E	IFC/NC	
European Utilities Requirements (EUR)	F1A (Automatic)	F1B (Automatic and Manual)	F2	Not Classified
UK	Category 1	Category 2	Not classified	
USA	1E	Non-nuclear safety		

FIG. 1.3. Safety Classification of Important Functions in NPPs.

Some examples of critical safety equipment in NPPs are the plant protection systems (PPS, also called reactor protection system or RPS) and the associated sensors such as the ex-core neutron detectors, primary coolant RTDs, and pressure, level, and flow transmitters in the primary and secondary systems. Most of this equipment is normally in the harsh environments in the reactor containment. As such, their ageing and obsolescence is of more concern to plant life extension than the I&C equipment that are in a mild environment outside of containment. It is for this reason that sensors such as RTDs and pressure transmitters (including level and flow transmitters) are often tested on a periodic basis to verify adequate performance during normal operation and to ensure availability for post accident conditions. The testing of these sensors includes response time testing, calibration, and monitoring the condition of their cables and connectors.

Another example of critical safety equipment to consider is the Engineered Safety Features Actuation System (ESFAS), which includes the Emergency core cooling system (ECCS), the emergency diesel generators (EDG), etc. Fig. 1.4 gives a detailed breakdown of the key components of a typical NPP. This report is more concerned with the components to the right of the figure under the category of safety systems.

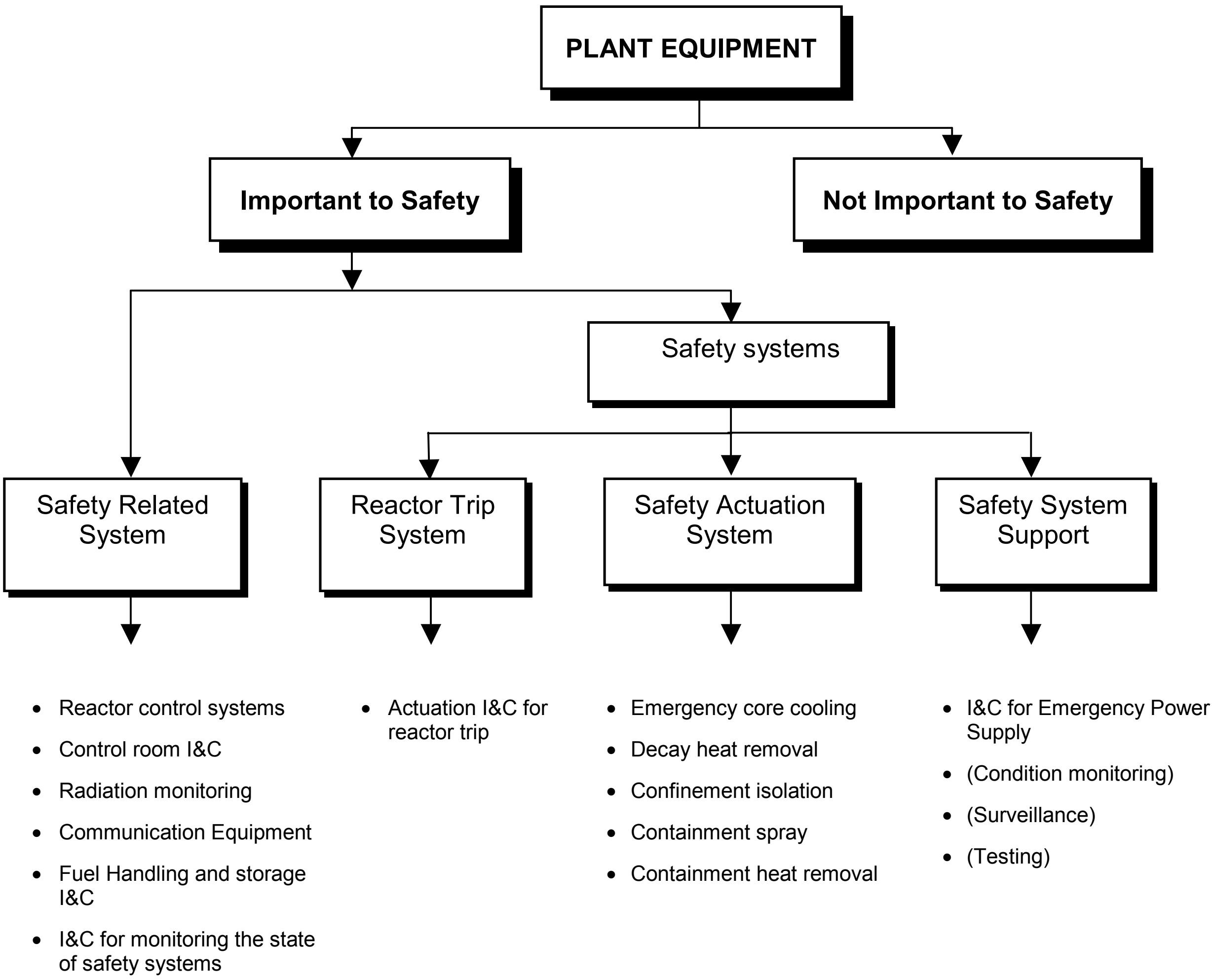

FIG. 1.4. Breakdown of Safety Equipment of an NPP.

1.5. RELATED PUBLICATIONS

A number of publications are already published or being written on the subject of I&C ageing and means to cope with this problem. The most notable of these is the IAEA-TECDOC-1147 [2]. The title of this TECDOC is Management of Ageing of I&C Equipment in Nuclear Power Plants and its publication date is June 2000. This TECDOC has been used as the basis for a new standard that is being developed under the auspices of the International Electrotechnical Commission (IEC). The title of the standard is *"Nuclear Power Plants - Management of Ageing and Obsolescence of Nuclear Power Plant Instrumentation and Control and Associated Equipment."* This standard is being prepared under IEC Subcommittee 45A Working Group A10. In addition, the IEC is preparing a related standard titled *"Nuclear Power Plant – Instrumentation and Control, Methods for Assessing the Performance of Instrument Channels in Systems Important to Safety."* This standard describes the test methods that shall be used to verify the performance of I&C equipment. It is being developed under IEC Subcommittee 45A Working Group A9. These standards were last discussed at the IEC meeting in Montreal, Canada in October 2003.

In addition to the above international publications, there are a number of research reports on ageing of I&C equipment in NPPs. This includes reports from the Electric Power Research Institute (EPRI) and the U.S. Nuclear Regulatory Commission (NRC). Most of these reports are identified in the bibliography section of this TECDOC. Chief among I&C ageing reports by the NRC are NUREG/CR-5560 on ageing of RTDs, NUREG/CR-5851 on ageing of pressure transmitters, and NUREG/CR-6343 as well as NUREG/CR-5501 on means to test the performance of ageing I&C equipment.

1.6. ORGANIZATION OF THIS TECDOC

This TECDOC is built on existing international experience from the worldwide nuclear power industry and researchers on I&C ageing and obsolescence, modernization and upgrades, safety and economic improvements, and recent activities toward long term operation and new reactor developments. It offers recommendations as to how to use existing and new predictive maintenance methods such as the noise analysis technique and on-line monitoring of existing plant signals to guard against I&C ageing and obsolescence while improving safety and the economic performance of NPPs. In doing so, the report takes advantage of a great number of existing reports, standards, and publications by the IAEA, NRC, EPRI, IEC, IEEE, ISA, and others. Rather than repeating from these existing and earlier works, this TECDOC includes a bibliography section to identify the most important documents that already exist on the issue of I&C ageing, obsolescence, modernization, life extension, on-line performance verification, incipient failure detection, and related subjects. In addition to the bibliography, this TECDOC contains a reference section where the specific publications referenced in the body of this report are listed.

Following the introduction, Chapter 2 contains material on understanding and on means to manage I&C ageing and obsolescence. The I&C components that were selected for this report are identified in Chapter 3. These components were selected based on their importance to plant life management and life extension and their ageing effects on plant safety, efficiency, and economic performance. This is followed by Chapter 4, which is devoted to a review of nuclear industry practices to address I&C ageing and obsolescence. In Chapter 5, the maintenance practice of the Beznau Nuclear Power Plant in Switzerland is used as an example of a proven method for I&C ageing management through compilation of existing knowledge, manufacturing data, analysis, examination, and performance of tests, such as response time measurements to verify proper equipment performance. In conjunction with Chapter 5, an annex is provided (Annex A) to include a typical Beznau procedure for equipment maintenance and ageing management.

In Chapter 6, the key recommendations of the TECDOC are presented. This is followed by references to provide a reference list of existing publications related to the subject of this TECDOC and a bibliography of publications for additional reading. Annexes given at the end of this report are intended for additional information, more details of certain areas of the report, and to include the “country reports”. The country reports included in this TECDOC were provided by those who served as members of the committee writing this report.

2. AGEING AND OBSOLESCENCE PROCESSES

2.1. BACKGROUND

The basic ageing and obsolescence management process involve:

- understanding the ageing and obsolescence phenomena and identifying the (potential) effects on I&C;
- addressing the specific impact of these effects on the plant taking into account operational profiles and analyzing the risks;
- carrying out necessary mitigating actions to counteract the effects of ageing and obsolescence.

This chapter gives some brief details about the understanding of ageing phenomenon.

Firstly, it has to be mentioned that the current understanding of ageing phenomenon is not complete. In general, many of the component materials used in I&C are of relatively recent origin compared to the life expectancies we are looking for in nuclear plant applications (e.g. first generation semiconductors 40 years, …).

The constantly evolving I&C product technology base (electronics/microelectronics) and the diversity of solutions implemented also mean that it is difficult to generalize the physical and functional consequences of individual material or component ageing on different I&C equipment. To a certain extent each plant I&C application has to be considered on a case-by-case basis. Similarly, the constantly evolving I&C product technology base (microelectronics and programmable systems) is a critical factor in the obsolescence problem.

Nevertheless, through various research programmes and general operating experience analysis we have a degree of knowledge of a number of generic ageing phenomena [4]. We are thus able to anticipate the potential effects of certain ageing phenomena. The applicability of these "known" phenomena to each type of I&C on the NPP must be established. The research and analysis programmes must be followed up or fresh ones may have to be instigated.

Concerning obsolescence, the support for legacy systems and the availability of replacement components is of course paramount. It is also necessary to maintain an awareness of the state-of-the art of I&C solutions, as well as possible future developments. In order to guard against all vulnerabilities and risks, the market trends in product supply and demand including the situation concerning the suppliers and other services (mergers, takeovers, line discontinuations) should also not be neglected.

The ageing and obsolescence management programme is thus going to be an iterative process.

2.2. UNDERSTANDING AGEING PROCESSES

2.2.1. I&C Ageing and Lifetime

The degradation of the performance or dependability of I&C equipment with time is understood by ageing. This degradation is due to physical mechanisms inherent to component materials and linked to the I&C equipment design, assembly and functional characteristics. It is influenced by the stresses from the equipment environment and from the equipment operation.

Wear-out and random failure are in fact due to some of the same phenomena. The ageing management process, however, considers more specifically the loss of the dependability of I&C systems and equipment a relatively long time from manufacture or installation. Wear-out should be considered more in terms of the parts that the design anticipates to be replaced during the I&C lifecycles (run to fail, corrective maintenance or preventive maintenance).

At the end of the I&C equipment's lifetime the failure rate of the component and hence the I&C equipment or system becomes greater ("bathtub" reliability curve). The reliability is no longer statistically predictable and hence the equipment becomes undependable. The influence of stresses from the equipment environment and from the equipment operation can effectively cause premature ageing.

Details concerning ageing phenomena can be found in the bibliographical references given in the Bibliography of this report. The following overview of the ageing process describes the phenomena in terms of stress factors, ageing mechanisms, and ageing effects on electrical equipment (IEEE1205). It should, of course, be remembered that some parts of I&C are not electrical; for example pneumatic valve actuators and some other mechanical/pneumatic instrumentation and controllers. These are not explicitly covered by this TECDOC (see Chapter 3). The IAEA TECDOC 1147 [2] also gives information on the ageing phenomena, their effects on I&C equipment and the status of associated research programmes.

2.2.2. Stress Factors Causing Premature Ageing

Stress factors originate from manufacture, pre-service, or in-service operating conditions. They produce wear-out failures and may induce ageing mechanisms and produce ageing effects. They can be considered as two types:

- *External stress factors* exist in the environment surrounding the equipment, whether it is operating or shut down. Typical examples include temperature, humidity, radiation, and vibration. Theses stress factors are continuous in time, but may vary in intensity depending on external events (climatic changes, plant events or hazards…)
- *Internal stress factors* arise from equipment or system operation. Examples are internal heating from electrical or mechanical loading, physical stresses from mechanical or electrical surges, vibration, and electrical or mechanical wearing of parts from equipment operation (e.g. contacts).

The ageing degradation of electrical or electronic equipment is a function of the duration, range and intensity of stresses experienced by the equipment. Ageing degradation due to a single stress factor may usually be represented as a simple first-order relationship involving the stress intensity and time; however, ageing degradation due to a combination of more than one stressor may exceed the sum of the individual effects [IEEE1205].

2.2.3. Ageing Mechanisms and Ageing Effects

By understanding the behaviour of the individual materials and components that make up the I&C equipment when subjected to external and internal stress factors, we can determine the susceptibility of equipment to ageing mechanisms and consequent ageing effects.

IAEA-TECDOC-1147 [2] provides details of typical ageing mechanisms and their effects on different I&C equipment families.

Some examples of stress factors, ageing mechanisms, and ageing effects are given as follows:

- High temperature environments can cause organic insulating materials to become brittle.
- Moisture or physical contact may result in a loss of dielectric integrity.
- High humidity can increase relay contact pitting and corrosion.
- High humidity or contact with water or chemicals can lead to corrosion of unprotected structures.
- High humidity environments can accelerate bearing wear in rotating parts without adequate seals or lubrication.
- Exposure to moisture can result in the delamination of insulated wires.
- Vibration and mechanical shock can result in a misalignment of components or loosen fixings and may cause loss of electrical contact integrity. Also metal fatigue in sensor components and cold working of wires may occur. Misalignment accelerates wear in moving parts; loose electrical contacts may lead to heat-related degradation; damage to electrical connections and displacement of insulation and connections will lead to electrical continuity/insulation problems.
- Radiation can break down the anti-oxidation chemicals in organic insulation materials and produce embrittlement similar to that caused by high temperature.
- Continuous operation of certain electronic components (e.g. diodes, resistors) at high ambient temperatures can cause equipment to run out of tolerances or performance specification, provoke circuit drift and may result in premature wear-out failure.
- Wear-out of semiconductor components are generally associated with such failure mechanisms as metal migration, hot electron effects, wirebond intermetallics, thermal fatigue. However, the current consensus is that these components (transistors, ICs) remain operationally stable for many decades within their nominal operating environment.
- Operation of electronic components above specified maximum supply voltage could induce wear-out mechanisms and reduce their life expectancy.
- Repeated maintenance operations entailing the withdrawal/reinsertion of electronic cards, ICs (e.g. EPROMs) and other semi-permanent connectors not specifically designed for repeated use can degrade electrical connections.
- Excessive voltage cycling can result in premature failure of electrolytic capacitors.
- Increased temperature accelerates the dominant ageing mechanism for capacitors with liquid electrolyte, which is loss of electrolyte through the end cap seal.

2.3. UNDERSTANDING OBSOLESCENCE PROCESSES

2.3.1. I&C Obsolescence

A lot of NPPs are currently operating using programmable electronic systems and equipment. Future NPP and retrofit projects will also use these types of devices, which are the state of the art solution for I&C. The lifecycle of such equipment has to be considered taking account of the specific characteristics of informatics technology (IT) and not be limited to the aspect of ageing of components (hardware). Some aspects of this are mentioned below.

- The component base for programmable I&C system products is less stable than that used for the older series of I&C (hardware using discrete components or simple integrated circuits). Rapid evolutions in the technology lead to a shortened life cycle for the commercial availability of processors, memories and peripheral devices.
- The state of the art I&C design moves rapidly compared to the NPP global life particularly on the IT side: software tools, Operating Systems (OS), engineering tools, HMI software.
- Specific problems can and have arisen due to disappearance and mergers of I&C equipment and component manufacturers.
- Human resource difficulties for the long term maintenance of software technologies are also important. IT career management is based on permanent updating of technologies while the NPP operation requires a «freezing» of technologies for compliance to safety regulation and operational cost reduction. Retaining expertise, and moreover creating a transmission of expertise, to counter the retirement of the original designers of the older I&C and IT will become more and more difficult in the future.

Thus, the ageing of programmable electronic devices is to be considered in the aspect of the long term operation and maintenance of equipment considering both hardware and software facets, and the human/organizational associated consequences.

2.3.2. Categorization of I&C Equipment and Systems Considering Lifetime Requirements

I&C systems can be made up of a diverse variety of individual pieces of equipment either available as off-the-shelf products or specifically developed items. The trend today is the application of standardized, integrated digital control system plate-forms, with possibly the use of different families of equipment according to the operational specifications and the safety requirements for each function to be implemented.

The design of NPP I&C systems is of course particular to a given plant or plant series. The I&C systems and equipment which are implemented for NPPs are related to the required functionality, safety importance and the availability of appropriate equipment solutions. However, some general aspects of the I&C architecture and functionality are typical to all NPP applications.

Traditionally, NPP I&C includes the following main functional components:

- Instrumentation and actuators. These are usually independent pieces of equipment. However, smart instruments and field bus, integrating higher level programmable functionality and communications, are now state of the art solutions for non-nuclear plants and increasingly being introduced into NPPs as either replacement parts or for modernization.

- Plant control systems (analogue modulating control, logic sequence control) can comprise discrete individual controllers, but are often integrated digital control system platforms in more recent plants.
- Limitation systems to avoid unnecessary solicitation of safety protection systems may be identified as a separate category of systems.
- Reactor protection and safeguard are independent to the control systems. The older systems were implemented as separate channels (analogue trip amps,..); but more recent systems comprise integrated digital programmed systems.
- Control room HMI equipment usually mixes discrete indicators and controls with integrated computerized systems, notably for plant supervision, data logging and alarms. Some examples of fully computerized control room HMI are now in operation.
- Modern digital control systems include the application engineering and testing tools used to produce and maintain the application software and the hardware configuration.

We need to consider the underlying «life cycle duration» associated to each category of programmable electronics:

- RPSs, due to sensitive aspects concerning safety regulations, are often considered under the responsibility of the reactor manufacturer and need lengthy, specific qualification process leading to a typical 2 to 3 decades range of service life.
- NPP control systems (modulating and logic control), based usually on programmable controllers from an industrial family of products, can be maintainable by the original manufacturer (if still present or represented on the market) by negotiating suitable maintenance contracts, for a typical 2 to 3 decades duration.
- Computer HMI systems and devices are the more versatile part, however the range of workstations and PCs has a shorter and shorter period of product commercialization (as low as 6 months....). This is short compared to the time needed for the design implementation of a control system (for a new plant or backfit) and very short compared to the expected commercial life of a NPP.
- Engineering tools include the hardware and software design tools needed to manage possible modification or extension for changes in plant operation, application programming tools and testing /commissioning tools. These tools are based on general purpose IT : OS /software suites/Database Management System (DBMS).

2.3.3. Organization for the Long term Maintenance of I&C Equipment to Cope with Obsolescence

A policy for long term maintenance needs to be organized by the plant operator/owner, involving the safety, economic and technical aspects.

This organization will be adapted to the local context, i.e.:

- the relationship with equipments manufacturers;
- the organization of the maintenance team;

- the number of plants equipped with the same ranges of equipments;
- the role of the plant operator in the technical maintenance tasks;
- the level of externalization of maintenance works.

This long term monitoring policy should include:

- contractual provisions with system builders and original equipment manufacturers;
- monitoring the life of the original equipment manufacturer;
- monitoring of obsolescence of components (software and hardware);
- economic analysis (cost of obsolescence / cost of induced plant unavailability).

These elements should be the basis for a strategic analysis of critical limits in terms of the maintainability of old equipment and the preparation of alternatives involving partial or full retrofit.

For a new plant design or for a major retrofit of control systems the recommended practices should be:

- selection of systems manufacturers involved in power plant control with a policy of technical continuity with regards to control system evolution;
- audit of the existing organizational procedures (state of the art) for long term;
- maintenance contracts from the equipment/system manufacturer;
- selection of IT tools based on the most industrially widespread basic tools;
- storage of components to constitute strategic spare part fund (note that ageing requirements may apply here);
- porting of engineering tools into new software environments.

2.3.4. Possible Organizations to Maintain a Skilled Team in a Long term Approach

An organization to maintain skill resources over the long term, led by the plant operator, in correspondence with the local safety authority organization and the equipment manufacturers could be based on:

- monitoring of market evolution;
- updating of knowledge from the original manufacturer;
- training on both old technology and current ones (to be ready for partial or large retrofit);
- periodic updating (with associated non regression tests) for the technologically "volatile" parts;
- preparation of alternatives for a retrofit either using partial equipment changes, or adaptation of existing equipment to new versions of a control system from the original manufacturer, or a full change. (Do this according to economic estimates, compared to

the cost of possible plant unavailability induced by the lack of spares or the lack of skilled teams both within the operational staff and within the original manufacturer's organization).

3. I&C COMPONENTS OF INTEREST

This chapter identifies the key I&C components that are subject to ageing degradation and/or obsolescence. In arriving at the list of I&C components, particular attention has been given to those components whose ageing or obsolescence can be detrimental to plant safety, efficiency, or economy and may have an impact on the ability of the plant to obtain a license renewal. Examples of means that may be implemented are given in this TECDOC to track the health and performance of I&C equipment and ensure that the availability of I&C equipment is not diminished not only for normal operation, but also and as importantly for accident recovery. It is understood that most I&C components are replaceable; nevertheless, ageing management is important to ensure that these components continue to respond in a timely and accurate manner as they age and to alleviate the fear that a fleet of I&C components can reach the end of life, experience common mode failure, and cause plant availability problems or fail to provide their intended function in case of an accident.

3.1. I&C WIRE SYSTEM

An example of an important regulatory concern with long term operation is the I&C wire system which includes cables, connectors, junction boxes, penetrations, etc. Aged I&C cables are expected to fully function to carry the I&C signals to a control room for normal operation, Design Basis Event (DBE) management and recovery, etc. The I&C wire system must be able to function properly up to the last day of normal operation, and during the post-accident monitoring period should a DBE occur at that time. Therefore, the cable degradation is an issue that must be addressed and the cable ageing monitoring means must be established to monitor the potential degradation.

The following paragraphs provide a review of cable testing techniques to verify that I&C cables are in good condition not only under normal operation but also for DBE and post-DBE service. Those who are interested in more information are referred to IAEA-TECDOC-1188 [3] and the publications that are listed in the bibliography section of this TECDOC.

The ageing of cable insulation or jacket material is important because aged cables can become hard and dry, can crack, which causes moisture intrusion into the cable resulting in corrosion, short circuits, shunting, and failure. In addition to the adverse effect on the plant operation and safety, such degradation or failure of cable insulation materials can be a fire hazard. In fact, fires have occurred in NPPs and other industrial processes where cables had become dry and ignited from electrical sparks. With these points in mind, this TECDOC will also discuss means of testing for embrittlement of cables and the susceptibility to moisture intrusion, short circuits, and fire.

A method referred to as the Time Domain Reflectometry (TDR) test is a popular cable testing technique. The TDR test is mainly useful to identify and locate problems in a cable conductor. Its results also provide information about insulation moistening as well as occurrence of insulation defects with low resistance (<0.5 k Ohm). At present, other electrical measurements such as capacitance, inductance, and resistance (LCR) measurements are also used in NPPs. However, these methods are mostly used when there are problems to be resolved with the I&C equipment and are not applied on a routine basis. Unfortunately, electrical measurements, such as TDR and LCR do not offer a strong means to register ageing of cable insulation at an early stage.

For today, generally accepted cable condition monitoring (CM) methods are mechanical measurement of hardness of the cable insulation material using such equipment as a cable indenter, velocity of propagation of ultrasonic waves through the cable, and chemical analysis involving microsamples, such as a few mg of cable insulation material. Examples of chemical analysis techniques are oxidation induction time/temperature (OIT) test, fourier transform infrared spectroscopy (FTIR), and nuclear magnetic resonance (NMR) measurement. The choice of CM technique is determined by type of cable insulation material and type of environmental stressors.

In some NPPs, spare inactive cables are deposited in high stress areas in the reactor containment and periodically removed and tested. This method provides for assessment of cables not only in normal operation but also under DBE and post-DBE service without a disruption of the operating cable lines. The condition of these spare cables is then assessed through the measurement of elongation-at-break of insulation material, insulation resistance measurements, and other cable testing techniques.

3.2. SENSORS AND TRANSMITTERS

Sensors (RTDs, thermocouples, neutron detectors), and transmitters (pressure and differential pressure transmitters that are used for measurement of not only pressure but also level and flow) should be included in an ageing management programme, especially for plants applying for life extension. This issue was also addressed in (IAEA-TECDOC-1147) [2].

Although sensors and transmitters can be replaced, it is important to verify their performance on a regular basis for a number of reasons. First, the performance of safety-related sensors is crucial to the PPS. Secondly, a large part of sensors operate in a harsh environment and are therefore subject to conditions that induce performance degradation. Third, as sensors age, their failure may accelerate rapidly causing multiple failures over a short period of time. Fourth, it is important to measure and track the performance of sensors for residual life estimation and replacement schedules.

Replacing a sensor is not always a prudent means for ageing management. This is because a sensor replacement does not necessarily guarantee adequate performance. Experience has shown that once sensors pass their infant mortality and burn-in period, one of the most effective means for sensor life management is performance testing on a regular basis. In fact, in some Member States, it is mandatory to measure the response time of sensors to ensure that no degradation is involved. Care should be taken to separate sensor problems from cable problems. In some plants, sensors, such as RTDs or thermocouples have been replaced to resolve a problem that was actually in the cable, not in the sensor. Therefore, if a measurement system is suspected of having problems, the cables and the sensors shall both be tested to determine the source of the problem before any correction action is taken.

3.3. PROCESS TO SENSOR INTERFACES

Process-to-sensor interfaces include thermowells that are used with temperature sensors, sensing lines that are used with pressure transmitters, etc. There are a number of problems that the nuclear industry has experienced with thermowells and sensing lines. For example, thermowells have been found to rupture and float in the reactor coolant system. This is obviously a problem of major concern. Thermowells are also responsible for response time degradation of temperature sensors. Under process operating conditions, such as vibration, temperature sensors can become loose in their thermowell and produce an air gap in the sensing tip of the sensor. The air gap will then cause the response time of the temperature sensor to increase; and this response time increase can be significant, depending on the magnitude of the air gap. In NPPs, temperature sensors have been found with response time that increased by an order of magnitude over a few operating cycles. The air gap in the thermowell can also result from manufacturing tolerances or RTD/thermowell mismatch. In some cases, RTDs are manufactured with gold or silver tips. As the tip erodes over time, the RTD response time can increase. Also, every time an RTD is removed from its thermowell and reinstalled, its response time may increase if it has a silver or gold tip. This is because the silver or gold layer is somewhat eroded with each removal and re-insertion. This can increase the air gap in the thermowell and cause the response time to increase.

Sensing lines that connect the process to pressure transmitters are prone to ageing degradation. For example, blockages can develop in pressure sensing lines over time and they can increase the time that it takes for a change in a pressure signal to be sensed. The amount of increase in response time that can result from a sensing line blockage depends on the compliance of the pressure transmitter. For those transmitters that have a large compliance, any significant blockage in the sensing line can result in a major increase in response time of the pressure sensing system.

Air or gas in pressure sensing lines can also cause problems. For example, air can cause noisy pressure signals and resonances in the sensing lines. Also, the response time of a pressure sensing system can increase with air or gas in the sensing line.

Neutron detectors are also not immune to degradation due to changes in the process to sensor interfaces. For example, water can accumulate in the well of neutron detectors and affects the sensor coupling to the process. In-core thermocouples are similarly prone to degradation in response time due to changes in the process-to-sensor interface. In some PWR plants of Russian design (WWERs), long thermocouples are inserted in long thermowells which extend into various regions of the core. Any significant air gap in these thermowells can cause a significant error in temperature measurement as well as a very large response time for the thermocouple.

3.4. ANALOG AND DIGITAL ELECTRONICS

In addition to sensors, the analogue and digital electronics that are used to convert the sensor signals, provide signal conditioning, and digitize the data should be included in the management of I&C ageing. This equipment has not in the past been the subject of ageing concerns because they are normally located in instrument cabinets in the mild areas of the plant, and consequently age very slowly. However, obsolescence of this equipment is important, especially as it relates to long term operation. Obsolescence is more of a problem with this equipment than ageing, because electronic components and digital systems are frequently upgraded by manufacturers, and older equipment is no longer available. Consequently, in the focus of ageing management for such systems, it is necessary to ensure that the required functions are met independent of the I&C technology applied.

Printed Circuit Boards (PCBs) are key components of digital I&C devices that are used in many applications in NPPs, and are composed of many integrated circuits (IC), electrical and electronic devices, and complex thin patterns for control signals and power. Electronic ageing mechanisms of these subcomponents have to be considered in addition to mechanical, chemical, and other ageing mechanisms, such as vibration during usage, removal for maintenance, etc.). PCBs should be a part of the ageing management programme. An example of an ageing management programme for PCBs is discussed in the Korean country report at the end of this TECDOC.

3.5. OTHER COMPONENTS

The above chapters provide examples of I&C components for which ageing is an issue and ageing management is thus important for normal operation, guarantee of safety, and justification of life extension. Additional types of I&C components may be in use, depending upon the plant type and various technologies that are employed in Member States. As such, a great number of other types of I&C equipment are used in various plants that are also subject to ageing and for which ageing management is important.

4. INDUSTRY ACTIVITIES TO COPE WITH I&C AGEING/OBSOLESCENCE

The worldwide nuclear industry has implemented a number of measures over the last ten years to deal with I&C ageing and obsolescence. Chief among these activities have been I&C modernization, research and development with regard to the ageing phenomenon, commercial dedication, use of digital equipment, life cycle and ageing management programmes of I&C systems and components, as well as activities related to the influence of license renewal in the I&C area.

4.1. I&C MODERNIZATION

As nuclear plants receive and/or seek licensing renewal and look forward to decades of continuing operation, they will inevitably continue the replacement of their ageing and obsolete I&C systems. However, these replacements will, for the most part, be phased in over several years, and careful planning and maintenance of ageing equipment will be needed in the meantime. A well-established modernization programme focuses on key issues that will impact the technical and financial success of the transition to updated I&C systems. Substantial topics under this programme will include LCM planning for I&C systems, ageing mechanisms of electronic components, guidelines associated with digital and hybrid (partly analogue, partly digital) systems, and cost effective requirements generation for digital upgrades. Complex modifications and system modernizations will generally affect the annual outage plan and the duration of the outage concerned. The preparation work and licensing of these complex design changes require significant and careful establishment activities.

I&C device and component backfits, i.e. the replacement of ageing transmitters, sensors, controllers, indicators and other individual parts of equipment can be implemented as continuous modernization activities with varied intensity during the service life of the NPP. Timing of these replacements should be designated in compliance with the documented qualified life of the component. Specific modernization plans should be developed for given groups of components (e.g.: pressure transmitters) or for given functions. In some nuclear plants initial device replacements may be justified by quality, reliability and maintenance aspects, but after reaching the required level, the approach will change to component replacement based on the documented qualified life.

For I&C modernization, the focus in several implementation projects has been the electronics, which convert the sensor readings to information that is used to monitor and control the plant and protect the plant safety. In doing so, many plants have not changed the sensors, although the sensors are the component of an instrument channel that reside in the field in the harsh environment. The reason for not changing the sensors is simple. Temperature is still measured with RTDs and thermocouples, and there is nothing new to take the place of these sensors. There are new fiber optic temperature instrumentations, but these are not mature enough at this point for NPPs. Also, smart temperature sensors have become available over the last decade, but these sensors use conventional RTDs or thermocouples as their primary sensing element. What is new in smart sensors is the memory that can hold information and the ability to add or subtract biases to bring the temperature reading to calibration and remote gain adjustment. The same is true about pressure and differential pressure sensors including level and flow sensors. Almost all pressure instrumentation in NPPs use essentially the same technologies (Bellows, Capacitance Bridge, Linear Variable Differential Transfer (LVDT), etc.) that have been in use for decades. As in the case of temperature sensors, there are fibre optic pressure sensors and smart pressure transmitters. The fibre optic pressure sensors are not yet mature enough for NPPs, and smart pressure transmitters still use conventional sensing elements such as capacitance cells as their primary sensing element.

Since most I&C modernizations do not involve the sensors, it is important to ensure that sensors are providing optimum performance and keep up with the improvement in electronics. For this, in-situ and on-line calibration and response time testing methods are used, such as the cross calibration technique for RTDs and thermocouples, on-line calibration monitoring techniques for pressure and differential pressure transmitters, and the Loop Current Step Response (LCSR) and noise analysis methods for response time testing of temperature and pressure sensors. With the application of these tests, one can verify that the sensor performance is in-line with the improved electronics that are installed in plants during I&C modernization and upgrade programmes. If the sensors are not providing accurate and timely readings, the rest of the instrument channel cannot correct for it, no matter how modern the channel might be. On the other hand, with a good sensor performance as verified by in-situ/on-line testing, improved measurements can be assured.

The replacement and modernization of I&C systems and components are discussed in details in several IAEA publications as listed in the bibliography of this TECDOC.

4.2. RESEARCH AND DEVELOPMENT ACTIVITIES

Component and structural material degradation occurs as a result of long term operation. This effect is accelerated in nuclear plants due to the exposure of materials to harsh environmental conditions. R&D conducted in several countries provides and will provide a better understanding of degradation mechanisms and how they occur, enabling development of cost effective ageing management strategies to prevent, detect or repair the effects of degradation.

The goal of these research programmes is to ensure that current nuclear plants can continue energy production up to and beyond their initial design life period by resolving critical issues related to long term plant operation.

Research on ageing mechanisms is conducted to understand, characterize, and manage or mitigate effects of plant ageing on — among others — I&C components, such as sensors, transmitters, electrical cables, electronic components, etc.

Specific examples related the R&D of the ageing mechanism are depicted in several documents listed in the Bibliography and also in material included in Annex B (see B.1) of this TECDOC.

4.3. COMMERCIAL DEDICATION

The obsolescence is more of a problem in the nuclear industry than in other industries. This is because the nuclear industry usually has very strict requirements for products that are used in systems that can affect safety. On the other hand, the quantity of components within a certain period of time that the nuclear industry needs is not so high to encourage long term production and support by manufacturers. Furthermore, once a nuclear plant is completed, most important I&C equipment will work well for a long period of time, and replacement needs are not widespread. Therefore, the combination of strict requirements and small demand make it unattractive for vendors to produce components for nuclear safety related applications and to provide continued support.

Over the last two decades, many major manufacturers of components for NPPs have ceased to supply or support products with which the plants were built. Pressure and differential pressure transmitters, for example, are extremely important to control and safe operation of nuclear plants. They are used to sense pressure, flow, and level in safety and non-safety applications. The majority of the current electronic devices has served the industry well but is based on designs from the 1970's. These devices are becoming obsolete and manufacturers will not produce them indefinitely. Modern designs with digital electronics are available; however, they were not proven for use in NPP applications. This moved the nuclear industry to take the responsibility to acquire commercial components and qualify them for nuclear applications.

Commercial dedication involves qualifying commercially made components to be used in NPPs. Commercial dedication is practiced in the nuclear industry mainly to cope with excessive costs involved in developing nuclear specific I&C applications. In this respect, commercial off-the-shelf (COTS) products are used in NPP applications. In doing so, utilities take upon themselves to qualify COTS for use in nuclear plant applications. Today, there is good experience with commercial dedication in the nuclear industry. Industry groups, such as EPRI and others have established the necessary guidelines for commercial dedication.

An example of commercial dedication for the Rosemount 3051C smart transmitter is described in Annex B (see B.2).

4.4. LIFE CYCLE MANAGEMENT

Life cycle management (LCM) is the integration of NPP engineering, operations, maintenance, licensing, economic planning, and other activities to achieve the following objectives:

1. manage material condition of the plant;
2. optimize operating life (including decisions, for license renewal or retirement); and
3. maximize plant value while maintaining safety.

Methods for LCM of important systems, structures and components, and information on application of tools for nuclear plant asset management in the new competitive environment are outlined in various chapters of this TECDOC.

An example of LCM of the Czech Škoda made control rod drives used in WWER reactors can be found in Annex B (See B.3).

4.5. AGEING MANAGEMENT PROGRAMME

With the increasing age of plants it is a requirement from the licensing authorities in most countries to establish an ageing management programme for the safety equipment. This can be found in the context of periodic safety review, requests for license renewal or long term operation. The ageing management requirements must be fitted also in the maintenance-programmes.

The goal is to preserve the functionality, performance and qualification for the safety systems and equipment during the whole operating time of the plant. All investigations, calculations and type-tests must be traceable to the installed equipment in the plant. The focal point is the safety equipment installed in harsh environmental conditions.

As an example, the establishment of an ageing management programme in the Kozluduy NPP can be found in Annex B (See B.4).

In a license renewal application, the demonstration of an appropriate ageing management process is a very substantial part. A basic method is the application of screening criteria to I&C components and the categorization of components based on ageing related aspects. Such screening criteria are established, for example, in the US NRC's 10 CFR 54.21(a)(1)(ii) document (see also [5,6]). If the component is included in the power plant's Environmental Qualification (EQ) Programme, then it has a documented qualified life. Components in the EQ Programme that have a qualified life less than the design life of the plant are replaced on the basis of a specified time period at the end of their qualified life. Components in the EQ Programme that have a qualified life based on the design life of the plant are the subject of time-limited ageing analysis. 10 CFR 54.21(a)(1)(ii) allows the exclusion of the component commodity groups that are subject to replacement based on a qualified life or specified time period.

Examples of the application of screening criteria can be found in Annex B (See B.5).

The methodology used for the ageing management review employs the "plant spaces" approach in which the plant is segregated into areas (or spaces) where common bounding environmental parameters can be assigned. Each bounding environmental parameter is evaluated against the most-limiting (worst-case) material in the area to determine if the components are able to maintain their intended functions through the period of extended operation. An appropriate guideline shall be used to identify ageing effects for all electrical commodity groups within the scope of this review. Potential ageing effects are based upon materials of construction and their exposure to environmental stressors, such as heat, radiation, and moisture. The ageing management review should identify one or more ageing management programmes to be used to demonstrate that the effects of ageing will be managed to assure the intended functions will be maintained for the period of extended operation.

As an example, typical stressors and ageing effects for cable components can be found in Annex B (see B.6).

4.6. ON-LINE TESTING AND CALIBRATION

Plant life management practices with respect to I&C equipment varies around the world. The variation ranges from periodic time-directed testing of the equipment, such as annual or bi-annual calibrations, response time measurements, cable testing, noise diagnostics, and other measures to simple tracking of the equipment performance by visual inspections, paper analysis, and other basic means. In some Member States, I&C equipment is only examined once every ten years, and in others, the same equipment is tested once every fuel cycle. As such, there is no international consensus as to how much and how often the I&C equipment must be response time tested, calibrated, or replaced to guarantee the public health and safety. What is well known regarding the performance of I&C equipment is that the majority of malfunctions and failures occur early in life. As such, burn-in tests are recommended. Also recommended are baseline measurements to characterize the performance of the I&C equipment when it is new. If baseline data is available on nominal performance of I&C, only changes from the nominal performance must be monitored. Unfortunately, the worldwide fleet of NPPs have not all recognized the benefits of baseline measurements. As such, when tests are performed, it is difficult to know whether the equipment is as good as new or performance degradation has occurred. In lieu of baseline, a good practice is to perform periodic measurements of response time, trending of calibration, testing of cables, and other activities of this sort to make sure that I&C equipment degradation is not occurring.

5. RELATIONSHIP BETWEEN AGEING, LIFE CYCLE MANAGEMENT, AND MAINTENANCE

The ageing management of I&C equipment can integrate with the overall plant LCM and directly lead to the definition of specific tasks in the maintenance programme. This strategy has been adopted in a number of NPPs, such as the Beznau nuclear power plant in Switzerland. Beznau is a two-unit Westinghouse PWR station that came to operation in the early 1970s. In this chapter, Beznau's practice is described as an example of a successful programme that has brought the ageing management of the I&C and the plant LCM issues into the scope of routine plant maintenance activities. This practice was established in the early 1990s, as the Beznau plant began to prepare for dealing with plant ageing concerns. This practice is used not only at the Beznau station but also at all other Swiss NPPs. The practice takes care of ageing and LCM and also provides input to the plant management as to what equipment must be replaced and when to replace the equipment.

Figure 5.1 illustrates Beznau's practice. As shown in this figure, there are five main tasks involved in the practice. These tasks are described in this chapter.

5.1. INFORMATION COMPILATION

For each equipment or system whose ageing and LCM is of concern, all relevant information is compiled through a comprehensive literature survey, interviews with experts including plant's own personnel as well as outside consultants, gathering of information from suppliers and vendors, review of industry standards and best-practices. For example, the following sources were used by Beznau to establish expected life of equipment, to develop new procedures, or complete/modify existing procedures for ageing and LCM of certain I&C equipment:

1. EPRI reports on equipment qualification and ageing (e.g. EPRI NP-558, EPRI/Holzmann report, and other EPRI Cable ageing reports).
2. Reports to the U. S. Nuclear Regulatory Commission (NRC) on I&C ageing (e.g. NUREG/CR-5560 on RTDs, and NUREG/CR-5851 on pressure transmitters).
3. Vendor manuals and equipment qualification reports (e.g. Company information on pressure transmitter characteristics, transmitter qualification requirements, information on response time testing of RTDs and pressure transmitters).
4. National laboratory reports (e.g. Sandia National Laboratory reports on characteristics of cables and description of cable testing methods such as measurement of elongation-at-break, Wyle Laboratory reports, etc.).
5. Interviews with plant maintenance staff, external consultants, discussions with other plants, technical conferences, short courses, and training seminars.
6. International reports and standards such as the reports of the IAEA and Standards of the IEC.
7. Textbooks on equipment ageing theory and calculation methods (e.g. Arrhenius theory).

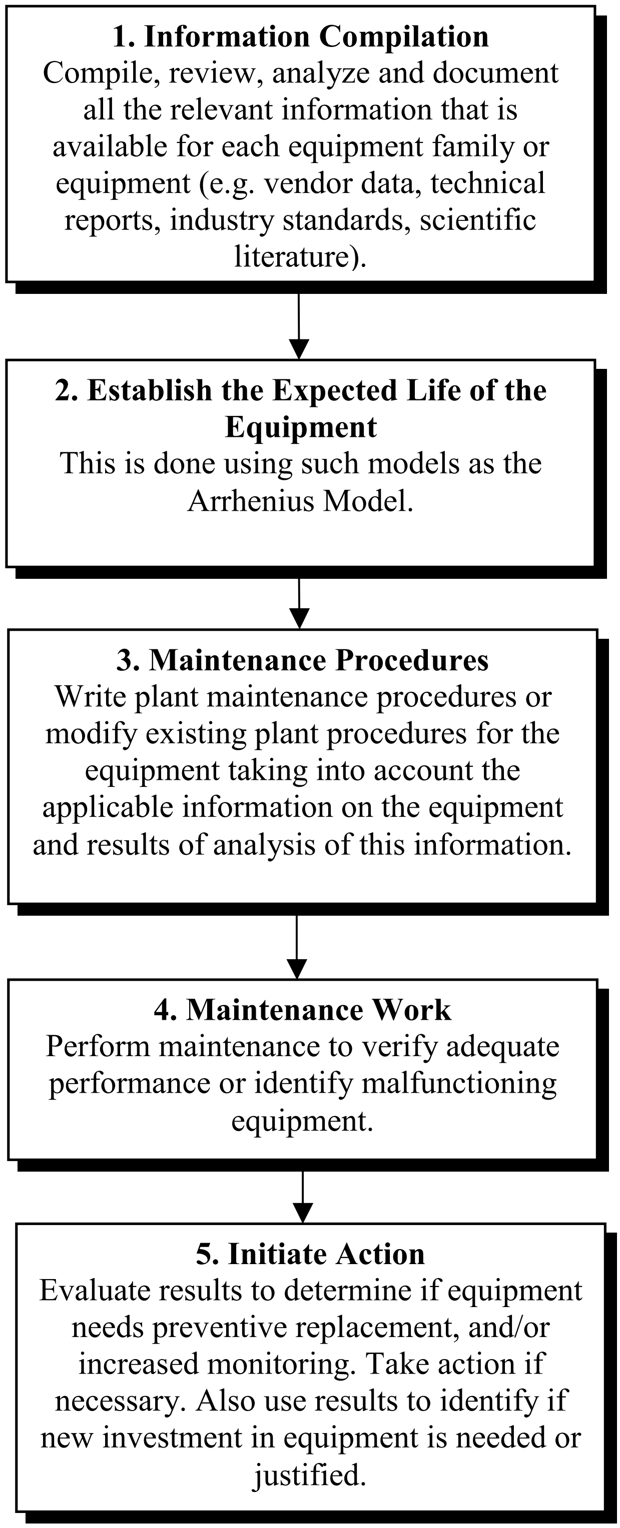

FIG. 5.1. Illustration of Beznau's Ageing and Life Cycle Management Practice.

This material was used by Beznau to extract specific information and data about qualified/expected equipment life, ageing mechanism, material properties, recommended replacement intervals, and test methods to detect degradation due to ageing. For example, based on literature on cable ageing, Beznau measures elongation-at-break as a means of testing the condition of cable insulation/jacket material. Also, the time domain reflectometry (TDR) test is performed on Beznau cables as needed. For RTDs, the Loop Current Step Response (LCSR) method is used to measure and track response time, and the noise analysis technique is implemented to test the response time of pressure, level, and flow transmitters and to identify blockages, voids, and other anomalies in pressure sensing lines.

The information from the above activities is organized and their validity and traceability is established, documented and maintained. Next, the ambient conditions that the equipment is exposed to are defined for normal operating conditions as well as accident conditions. In particular, attention is paid to whether the equipment is installed in a mild environment or in a harsh environment and the potential conditions around the equipment during and after an accident (LOCA and Post-LOCA). This is important because any maintenance programme for equipment ageing and LCM should take into account the normal, accident, and post-accident conditions that the equipment might experience throughout the life of the equipment or the plant.

5.2. ESTABLISHING THE EXPECTED LIFE OF EQUIPMENT

Beznau uses ageing models such as the Arrhenius theory to calculate the theoretical life of equipment. This information is then used to determine the maintenance programme that is most suitable for the equipment. The records of maintenance and the results of tests of the equipment are kept and trended as necessary until the end of the calculated/qualified life. At that point, an evaluation is made on whether or not the equipment must be replaced or the plant can continue to use the equipment beyond its calculated/qualified life. If the maintenance records, test results, and performance trends do not indicate significant degradation, then the equipment may not be replaced. That is, if natural ageing of the equipment does not produce any significant sign of ageing or degradation, no action is taken at the end of the calculated life. The same approach is used in dealing with equipment that is limited in the number of operating cycles. That is, regardless of the number of cycles that the equipment has operated, its replacement schedule is set based mainly on the condition of the equipment rather than on how long or how many cycles it has operated.

In determining the usage time of the equipment or determining residual life, other important information is also used, such as:

- Meantime between failures that provides an indication of reliability of the equipment.
- Environmental conditions other than temperature (e.g., radiation, vibration levels, humidity).
- Supplier availability to provide spare parts and technical support.

Determining equipment useful life is not limited to the plant life span alone. For those equipment that are needed during and after decommissioning (e.g. radiation monitoring equipment), provisions must be included in the maintenance programme to ensure that these devices and systems will perform their function well and safely during and after decommissioning.

5.3. NEW OR MODIFIED MAINTENANCE PROCEDURES

Following the compilation, review and analysis of all available information about the equipment as described in Sections 5.1 and 5.2, a new maintenance procedure is developed or the existing maintenance procedure is modified as necessary for the equipment to account for ageing degradation. This development begins with an evaluation of what maintenance methodologies are most appropriate for the equipment. The options here are condition based maintenance, time based maintenance, or corrective maintenance (run to failure). The safety classification of the equipment is, of course, taken into account in determining the maintenance methodology. For example, non-safety equipment is restored after a failure has occurred while safety equipment normally requires periodic maintenance. For periodic maintenance, the interval is selected based on the importance of the equipment to the plant safety, the consequences of exceeding a safe performance limit, potential rate of equipment performance degradation (if known), etc. For example, an RTD that feeds the safety system of the plant must respond quickly even to a relatively rapid change in temperature and it must also be accurate. Therefore, periodic response time testing and calibration verification is important for the safety system RTDs. Accordingly, at Beznau, response time measurements are performed on primary coolant RTDs to make sure that the RTD response time meets the safety limit.

Similarly, the response times of pressure, level, and flow transmitters at Beznau are measured to verify adequate dynamic performance, ensure that the pressure sensing lines are not blocked, and to identify voids, valve problems, and other anomalies that can compromise the performance of the pressure sensing system. These tests are important because RTDs and pressure transmitters are installed in the reactor containment and are subject to harsh environments. Furthermore, some RTDs and pressure transmitters are expected to operate properly not only during normal plant operation but also during and after an accident. It comes from the accident and post–accident requirements, specifying that RTDs and pressure transmitters be qualified to work under a Loss of Coolant Accident (LOCA) and Post-LOCA conditions. Note that being qualified for LOCA and/or Post-LOCA conditions does not reduce the requirement to verify the static and dynamic performance of these sensors on a periodic basis.

For safety related I&C equipment that are in a mild environment, periodic maintenance is also necessary. In mild environments, such as outside the reactor containment, the ambient conditions during an accident are almost the same as in normal operation. That is, the ambient temperature is between 10 and 45°C with normal ambient pressure, humidity, and low radiation. Examples of equipment that are in mild environments are instrumentation cabinets, electronic boards, batteries, and power supplies. Example of I&C components that are in harsh environments are RTDs, pressure transmitters, thermowells, hydrogen sensors, and wire systems including cables, connectors, penetrations, and junction boxes. If equipment is in a mild environment, then the maintenance programme is not as stringent as when the equipment is in a harsh environment.

5.4. MAINTENANCE WORK AND INITIATION OF ACTIONS

Figure 5.2 shows a block diagram representing the Beznau's maintenance practice. The practice is divided into two categories labeled by Beznau as preventive maintenance and corrective maintenance. The path of corrective maintenance is straightforward as shown in Fig. 5.2. That is, the equipment is operated as long as possible and once it fails, an action, such as an analysis is initiated to understand the reason for the failure and to help in correcting the problem. The problem is typically corrected by repairing the equipment, replacing the equipment, or overhauling the system as necessary.

Under preventive maintenance, there are two options depending on the equipment and its safety significance. These options are periodic maintenance, as well as predictive, or condition based maintenance. Periodic maintenance is performed at fixed intervals and may include periodic servicing, replacement, or calibration. Periodic maintenance is performed regardless of the condition of the equipment. That is, both new and old equipment are tested at fixed intervals.

Predictive maintenance often consists of passive tasks to identify the onset of potential failures. For example, equipment condition monitoring is performed and the results are compared with a baseline or previous information to determine if any significant change is occurring in the equipment. If a significant change is identified, then more testing is performed to determine if the equipment needs to be repaired or replaced. An example is the Time Domain Reflectometry (TDR) testing of cables. This test is performed at Beznau to determine if cable signatures are changing. Also, elongation-at-break tests are performed on cables that are retrieved from cable depots at Beznau to make sure that ageing has not caused degradation in the cable insulation material. Maintenance, such as equipment repair or replacement is conducted once the equipment has failed, exceeded its performance limit, or is found to be proceeding toward failure.

5.5. STEPS IN AGEING MANAGEMENT PROGRAMME IMPLEMENTATION AT BEZNAU

Beznau's ageing management strategy for the I&C equipment is implemented through the execution of the following steps (See Fig. 5.3):

Step 1. Identify equipment whose ageing is of concern to safety

In this step, all equipment whose performance or ageing degradation can be detrimental to safety is identified. This list consists mostly of class lE equipment (equipment for nuclear safety systems).

Once the equipment is identified, a list is prepared by tag numbers, name of equipment, location in the plant, and safety function (Fig. 5.4). The list is prepared based on ranking of various equipment in terms of their effect on plant safety. Then, the relevant safety functions and associated criteria for the equipment are identified (e.g. open/close for a solenoid operated valve, maximum operation time during an accident, …).

Step 2. Categorize equipment

The equipment identified for ageing management is then categorized into families of equipment. For Beznau and other Swiss plants, there are 32 families of equipment that have been determined to affect safety and their ageing degradation must, therefore, be monitored and maintained throughout the life of the plant. Examples of categories are:

- Wire Systems (cables, connectors, splices, penetrations).
- Sensors (RTDs, pressure transmitters, hydrogen sensors).
- PCBs and electronic modules.
- Electrical components (Relays and power supplies).

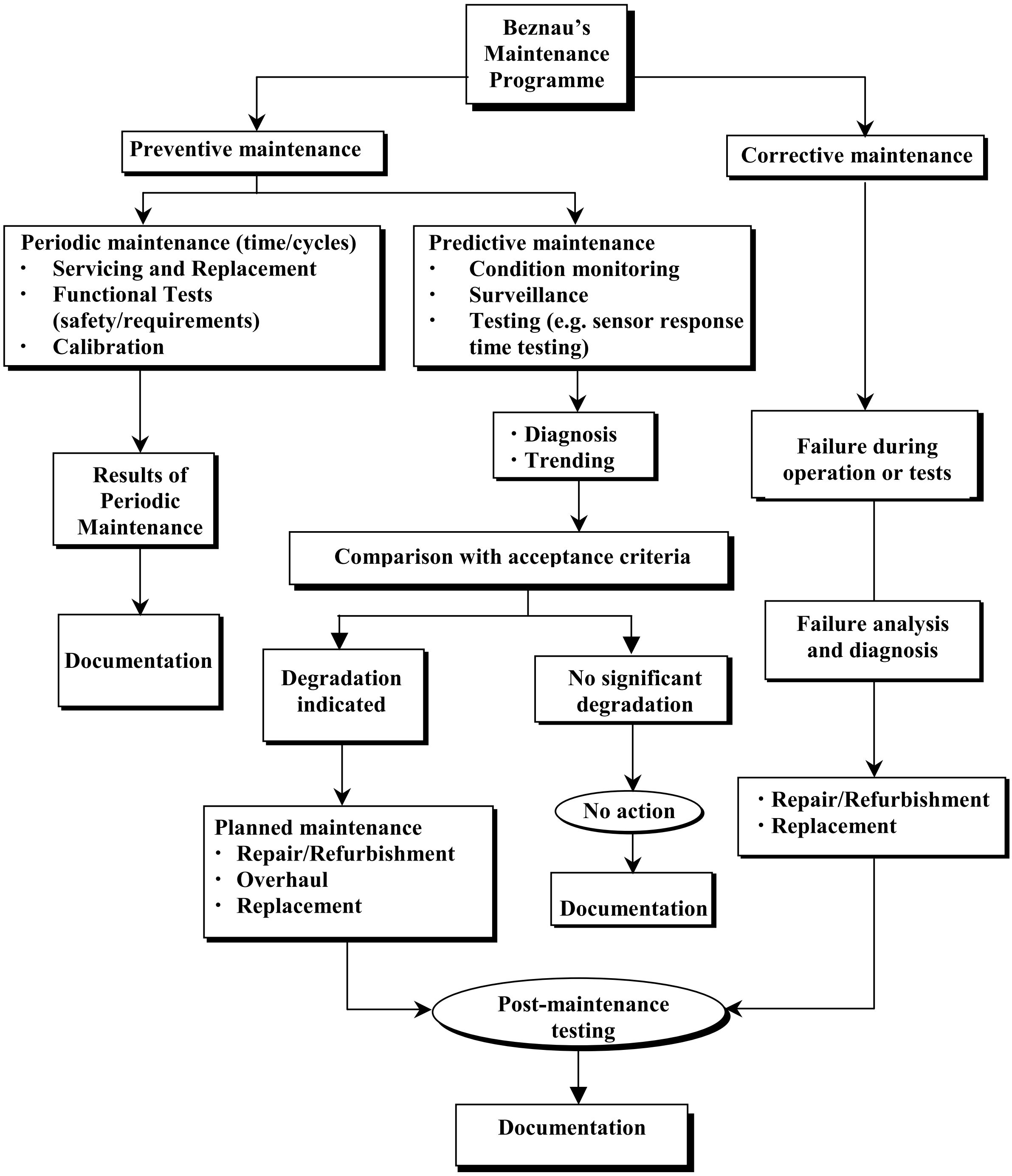

FIG. 5.2. Block Diagram of Beznau's Maintenance Programme.

Step 3. Identify equipment ageing mechanisms and ageing stressors

The ageing mechanism for equipment or family of equipment is determined from a comprehensive review of all available information that has been complied. Also, the stresses that can accelerate the ageing process are identified for all equipment, family of equipment, or ageing sensitive parts. Also state of the art diagnostic methods are identified to verify the performance of each equipment or family of equipment.

Step 1
Prepare a list of equipment and systems that should be included in the ageing management programme (Prepare the list considering the safety classification of the equipment).

↓

Step 2
Combine the list in terms of equipment families/categories.

↓

Step 3
Determine ageing mechanisms and ageing stressors that can cause performance degradation in the equipment and state-of-the-art diagnostic methods that can be used to verify that ageing has not degraded the equipment performance to an unacceptable level.

↓

Step 4
Perform a review of inventory and condition of equipment that is currently installed in the plant and the plant maintenance practice for preservation of this equipment.

↓

Step 5
Implement state-of-the-art testing, measurement, and diagnostic methods in the plant maintenance programme or maintenance procedures of the equipment that is important to plant safety.

↓

Step 6
Document the results and use this information to decide if/when equipment must be replaced or repaired/or the maintenance programme modified.

FIG. 5.3. Steps for Implementation of the Ageing Management Programme at Beznau.

AN-402-EQ94001 S-AÜP: Transmitter inside Containment

Equip.N°	Name of Equipment	Serialnr	Manufacturer	Type	in Operation	Techn.Place		Room		QG	SK	Qual.
505806	TRANSMITTER	0504786	ROSEMOUNT	1154-HP5	01.04.1993	**10JRC FT 0415**	TRANSMITTER DURCHFLUSS LOOP A	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505805	TRANSMITTER	0504787	ROSEMOUNT	1154-HP5	01.04.1993	**10JRC FT 0416**	TRANSMITTER DURCHFLUSS LOOP A	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505804	TRANSMITTER	0504799	ROSEMOUNT	1154-HP5	01.04.1993	**10JRC FT 0417**	TRANSMITTER DURCHFLUSS LOOP A	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505803	TRANSMITTER	0504800	ROSEMOUNT	1154-HP5	01.04.1993	**10JRC FT 0425**	TRANSMITTER DURCHFLUSS LOOP B	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505802	TRANSMITTER	0504801	ROSEMOUNT	1154-HP5	01.04.1993	**10JRC FT 0426**	TRANSMITTER DURCHFLUSS LOOP B	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505807	TRANSMITTER	0503218	ROSEMOUNT	1154-HP5	01.04.1993	**10JRC FT 0427**	TRANSMITTER DURCHFLUSS LOOP B	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505759	TRANSMITTER	0504776	ROSEMOUNT	1154-HP5	01.04.1993	**10JRC LT 0459**	TRANSMITTER NIVEAU DRUCKHALTER	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505758	TRANSMITTER	0504777	ROSEMOUNT	1154-HP5	01.04.1993	**10JRC LT 0460**	TRANSMITTER NIVEAU DRUCKHALTER	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505757	TRANSMITTER	0504780	ROSEMOUNT	1154-HP5	01.04.1993	**10JRC LT 0461**	TRANSMITTER NIVEAU DRUCKHALTER	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505755	TRANSMITTER	0504781	ROSEMOUNT	1154-HP5	01.04.1993	**10JRC LT 0462**	TRANSMITTER NIVEAU DRUCKHALTER	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505777	TRANSMITTER	0504491	ROSEMOUNT	1154-DP4	01.04.1993	**10JRC LT 0480**	TRANSMITTER NIVEAU DE-A	1S501	BEDIENUNGSBODEN KOTE 340.00	A	1E	VOLL
505776	TRANSMITTER	0504492	ROSEMOUNT	1154-DP4	01.04.1993	**10JRC LT 0481**	TRANSMITTER NIVEAU DE-A	1S501	BEDIENUNGSBODEN KOTE 340.00	A	1E	VOLL
505775	TRANSMITTER	0504493	ROSEMOUNT	1154-DP4	01.04.1993	**10JRC LT 0482**	TRANSMITTER NIVEAU DE-A	1S501	BEDIENUNGSBODEN KOTE 340.00	A	1E	VOLL
505687	TRANSMITTER	0504788	ROSEMOUNT	1154-DP5	01.04.1993	**10JRC LT 0483**	TRANSMITTER NIVEAU DE-A	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505774	TRANSMITTER	0504610	ROSEMOUNT	1154-DP4	01.04.1993	**10JRC LT 0490**	TRANSMITTER NIVEAU DE-B	1S501	BEDIENUNGSBODEN KOTE 340.00	A	1E	VOLL
505771	TRANSMITTER	0504628	ROSEMOUNT	1154-DP4	01.04.1993	**10JRC LT 0491**	TRANSMITTER NIVEAU DE-B	1S501	BEDIENUNGSBODEN KOTE 340.00	A	1E	VOLL
505770	TRANSMITTER	0504629	ROSEMOUNT	1154-DP4	01.04.1993	**10JRC LT 0492**	TRANSMITTER NIVEAU DE-B	1S501	BEDIENUNGSBODEN KOTE 340.00	A	1E	VOLL
505686	TRANSMITTER	0504789	ROSEMOUNT	1154-DP5	01.04.1993	**10JRC LT 0493**	TRANSMITTER NIVEAU DE-B	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505701	TRANSMITTER	0504927	ROSEMOUNT	1154-SH9	01.04.1993	**10JRC PT 0455**	TRANSMITTER DRUCK DRUCKHALTER	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505698	TRANSMITTER	0504959	ROSEMOUNT	1154-SH9	01.04.1993	**10JRC PT 0456**	TRANSMITTER DRUCK DRUCKHALTER	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505697	TRANSMITTER	0504960	ROSEMOUNT	1154-SH9	01.04.1993	**10JRC PT 0457**	TRANSMITTER DRUCK DRUCKHALTER	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505696	TRANSMITTER	0504980	ROSEMOUNT	1154-SH9	01.04.1993	**10JRC PT 0458**	TRANSMITTER DRUCK DRUCKHALTER	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505747	TRANSMITTER	0504494	ROSEMOUNT	1154-DP7	01.04.1993	**10JSI FT 0920**	TRANSMITTER DURCHFLUSS	1S203	RAUM ABLASSNACHKÜHLER	A	1E	VOLL
505746	TRANSMITTER	0504495	ROSEMOUNT	1154-DP7	01.04.1993	**10JSI FT 0921**	TRANSMITTER DURCHFLUSS	1S203	RAUM ABLASSNACHKÜHLER	A	1E	VOLL
505745	TRANSMITTER	0504496	ROSEMOUNT	1154-DP7	01.04.1993	**10JSI FT 0922**	TRANSMITTER DURCHFLUSS	1S203	RAUM ABLASSNACHKÜHLER	A	1E	VOLL
505744	TRANSMITTER	0504497	ROSEMOUNT	1154-DP7	01.04.1993	**10JSI FT 0923**	TRANSMITTER DURCHFLUSS	1S203	RAUM ABLASSNACHKÜHLER	A	1E	VOLL
505798	TRANSMITTER		ROSEMOUNT	1154-DP5	01.04.1993	**10PRW FT 5513**	TRANSMITTER DURCHFLUSS 10SHV	1S501	BEDIENUNGSBODEN KOTE 340.00	A	1E	VOLL
505800	TRANSMITTER		ROSEMOUNT	1154-DP5	01.04.1993	**10PRW FT 5514**	TRANSMITTER DURCHFLUSS 10SHV	1S501	BEDIENUNGSBODEN KOTE 340.00	A	1E	VOLL

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FIG. 5.4. Typical Listing of Equipment that is Included in the Ageing Management of a Beznau Unit.

Step 4. ***Review the condition of installed equipment and their existing maintenance procedures***

For plants, such as Beznau and other plants in Switzerland, which have been in operation for a number of years, a review of the condition of existing plant equipment and its maintenance procedures is important. Therefore, to establish its ageing management programme, Beznau performed a review of its existing equipment and their maintenance procedures. This review provided the following information.

1. Equipment manufacturers, models, spare parts inventory
2. Results of equipment qualification and predicted life under actual plant operating conditions
3. Evaluation of current plant practice to maintain the equipment and verify its performance
4. Identification of any deficiencies in plant maintenance practice to address ageing

Annex A provides an example of a Beznau procedure for I&C ageing management.

Step 5. Test and diagnostic methods to manage ageing

The nuclear industry, researchers, and vendors continue to identify and develop means to verify the performance of NPP equipment. As a result, measurements, tests, and diagnostic methods are available to measure and track the degradation of most equipment in NPPs. These means are identified and used by Beznau for the management of ageing of I&C equipment and other plant components (see Annex A).

Step 6. Document the results and make decisions

Based on the above five steps, all the results are documented and this information is used to decide if/when equipment must be replaced or repaired.

5.6. EXTENDING THE LIFE OF EXISTING EQUIPMENT

A number of measures are taken at Beznau to preserve I&C equipment and to help extend the life of the equipment. For example, improving air conditioning of I&C equipment is a good practice to avoid premature ageing. According to the widely applied (Van't Hoff) 10°C rule, the theoretical age of equipment can be increased by a factor of 2 for each 10°C increase in the temperature of the environment in which the equipment is operated.

To preserve cables, they are kept as far away as possible from hot spots and sources of heat such as motor air outlets and hot piping. As for sensors, such as RTDs, pressure transmitters, trending of performance indicators such as response time may be used to determine if and when the sensor should be repaired or replaced.

There are other measures to ensure a long equipment life. For example, when replacing parts, Beznau uses the same parts from the same manufacturer, as much as possible. If this is not possible, the best alternative is used. Also, any parts or components that have been in storage for a long time must be evaluated for pre-ageing before they are used.
Some examples are electrolytic capacitors, grease that is used in Solenoid Operated Valves (SOVs) and switches, rubber sealings, and power supplies. These components are susceptible to pre-ageing in storage.

6. KEY RECOMMENDATIONS

Ageing effects on I&C should be assessed and adequate measures shall be taken to address potential safety problems. The effects of I&C ageing can be managed by the existing organization for plant maintenance through the adaptation of strategies and test methods of the type that are described in this report.

Research of ageing mechanisms is performed to understand, characterize, and manage or mitigate effects of plant ageing on — mong others — &C components, such as sensors, transmitters, electrical cables, electronic components, etc. Coordinated R&D programmes are recommended for a better understanding of degradation mechanisms and to enable the development of cost effective ageing management strategies.

Basic documentation and information required for I&C ageing management includes data relative to the qualified life and expected life of equipment, as well as qualification data for harsh and mild environment. Additional data and documentation are related to equipment life history from the time of manufacture to decommissioning, including diagnostic information to facilitate monitoring the ageing progress. All these data and documentation should be carefully prepared and maintained, should provide for traceability and should be preserved for the entire life of the equipment.

Increasingly, new digital I&C components are being recognized as providing advantages over older technologies, and are being installed as upgrades to aged or obsolete I&C equipment and systems. In view of this, utilities should establish plant related management processes to cope with the obsolescence and ageing of I&C systems.

Ageing anagement should be started as early as possible, preferably before the installation of I&C equipment.

In the case of replacing aged or obsolete I&C systems, the future costs for age management should be considered in addition to the initial investment costs, for the assessment of competing solutions.

It has been recognized that I&C equipment experiences ageing stress not only as installed in the plant, but also while in storage as spare parts. This phenomenon should be taken into account when determining the residual life of equipment.

A number of techniques have been developed worldwide which offer in-situ and online testing capabilities to verify the performance of I&C equipment including sensors and transmitters, wire systems, process-to-sensor interfaces, etc. These methods should be implemented to make sure that ageing does not affect the reliability, performance and integrity of the sensors and I&C systems.

In some NPPs spare inactive cables and connectors are deposited in high stress areas in the reactor containment and periodically removed and tested. The condition of these spare cables is then assessed through the measurement of elongation-at-break of insulation material, through insulation resistance measurements, and other cable testing techniques. This method can be recommended for each plant for a better-established life cycle management of wire systems. To preserve cables, they should be kept as far away as possible from hot spots and sources of heat, such as motor air outlets and hot piping.

The maintenance practice of the Beznau Nuclear Power Plant in Switzerland can be recommended as an example of a proven method for I&C ageing management through the compilation of existing knowledge, manufacturing data, analysis, examination, and the performance of on-line tests to verify proper equipment performance.

Although sensors and transmitters can be replaced, it is important to verify their performance on a regular basis.

Obsolescence of electronic equipment and digital systems is important, especially as it relates to plant life extension. Obsolescence is more of a problem with this equipment than ageing, because electronic components and digital systems are frequently upgraded by manufacturers, and older equipment is no longer available. Consequently, in the focus of ageing management for such systems, it is necessary to ensure that the required functions are met.

A well-established modernization programme focuses on key issues that will impact the technical and financial success of the transition to updated I&C systems. Substantial topics under this programme will include LCM planning for I&C systems, ageing mechanisms of electronic components, guidelines associated with digital and hybrid (partly analogue, partly digital) systems. Specific modernization plans should be developed for given groups of components or for given functions.

It is important to ensure that sensors are providing optimum performance and keep up with the improvement in electronics. For this, in-situ and on-line calibration and response time testing methods can be used, such as the cross calibration technique for RTDs and thermocouples, on-line calibration monitoring techniques for pressure and differential pressure transmitters, and the Loop Current Step Response (LCSR) and noise analysis methods for response time testing of temperature and pressure sensors.

Strict requirements and small demand have made it unattractive for vendors to produce components for nuclear safety related applications and to provide continued support. Therefore, commercial dedication is practiced in the nuclear industry mainly to cope with excessive costs involved in developing nuclear specific I&C applications. Commercial dedication should be considered as a cost effective option in modification and replacement projects.

The majority of malfunctions and failures occur early in life. As such, burn-in tests are recommended. Also recommended are baseline measurements to characterize the performance of the I&C equipment when it is new.

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ABBREVIATIONS

CM	Condition Monitoring
COTS	Commercial off-the-Shelf
CRDM	Control Rod Drive Mechanism
DBE	Design Basis Event
DBMS	Database Management System
ECCS	Emergency Core Cooling System
EDG	Emergency Diesel Generator
EPROM	Erasable Programmable Read-only Memory
EQ	Equipment Qualification
ESFAS	Engineered Safety Features Actuation System
EUR	European Utility Requirements
FTIR	Fourier Transform Infrared Spectroscopy
HMI	Human-Machine Interface
I&C	Instrumentation and Control
IC	Integrated Circuit
1E	Classification of Safety Equipment
IEC	International Electrotechnical Commission
IT	Information / Informatics Technology
LCM	Life Cycle Management
LCSR	Loop Current Step Response
LOCA	Loss of Coolant Accident
LVDT	Linear Variable Differential Transfer
MOV	Motor Operated Valve
NMR	Nuclear Magnetic Resonance
NPP	Nuclear Power Plant
OIT	Oxidation Induction Time Testing or Oxidation Induction Temperature Testing
OS	Operating System
PC	Personal Computer
PCB	Printed Circuit Board
PPS	Plant Protection System
PWR	Pressurized Water Reactor
R&D	Research and Development
RPS	Reactor Protection System
RTD	Resistance Temperature Detector
SG	Steam Generator
SOV	Solenoid Operated Valve
SSCs	Structures, Systems, and Components
TDR	Time Domain Reflectometry
WWER	PWR Plants of Russian Design

ANNEX A

EXAMPLE OF A MAINTENANCE PROCEDURE AT THE BEZNAU NPP IN SWITZERLAND

This annex contains the ageing management procedure of the Beznau plant for pressure transmitters. It is included here as an example of a model for other plants who may be interested in adopting the Beznau practice. The Beznau practice has been in place for nearly 10 years and has shown success in meeting the objective of routine maintenance and ageing management.

GSKL - FACHTEAM AÜP E - Technik	**REVIEW OF AGEING MANAGEMENT** **Equipment: Pressure Transmitter**	Number: **X 001/1** Plant spec. ID No. Page 1 of 3	Rev.
			1

P A R T 1 : A G E I N G M E C H A N I S M

E X A M P L E

L I S T O F C O N T E N T S

A: Equipment Information

Equipment:

Pressure Transmitter

REMARKS:

DISTRIBUTION: KKB: Electrical Department KKG: Electrical Department
KKL: Electrical Department KKM: Electrical Department

Revision:

1) Add informations according BP-092-EQ99001 chapter 3.1 — 1

	Name	Date	Rev. No.	1					
			Date	20.05.99					
Written by	sig. gf	12.12.94	Written by	sig. FD					
Checked by	sig. th	12.12.94	Checked by	sig. bgy					

GKSL-FACHTEAM AÜP E - Technik	**REVIEW OF AGEING MANAGEMENT** **Equipment: Pressure Transmitter**	Number: **X 001/1** Plant spec. ID No. Page 2 of 3	Rev. 1

B: Ageing mechanism with conditions

E X A M P L E

Equipment, Part	Material	Ageing mechanism	Ref	Conditions	Rev.
Electronic board with parts		Corrosion, Oxidation Chemical Effects Loosening of Conductor Embrittlement Change of electrical property	C 5 C 4	 Radiation	1 1
Soldered joint		Oxidation Corrosion	C 5		1
Plug-in contact, clamping connection	Cooper, gold-plated	Corrosion, Oxidation Wear	C 1 C 2	Humidity Vibration Plug/unplug cycles	
Potentiometer		Oxidation Corrosion Erosion Wear	C 5		1
Cover seal		Deformation Embrittlement Hardening Cracking	C 1 C 3	Pressure, Compression Radiation Temperature Humidity	1
Cable connection with penetration		Corrosion Oxidation Embrittlement	C 1	Vibration Humidity Temperature, Radiation	
Pressure-cell		Tightness Fatigue Wear Corrosion	C 1 C 6	Over-pressure Leakage of valves or pipes Temperature Vibration Boric acid Pressure surge (pulsation) Quality of flow medium	
Measure-pipe with screwed gland		Tightness Corrosion Fatigue Loosing of Fittings	 C 1	Quality of flow medium Boric acid Pressure surge (pulsation) Vibration	1
Valves		Tightness Wear Corrosion Fatigue	 C 6	Over-pressure Quality of flow medium Pressure surge (pulsation) Vibration Temperature Boric acid	

C: Documentation / Reference to Ageing Mechanism

_E X A M P L E_

Ref.	Title	Number	Place of deposit	Info-Contents	Rev.
C 1	Long Term Performance and Ageing Characteristics of Nuclear Plant Pressure Transmitters	NUREG/CR-5851 (NRC – Hashemian) NUREG/CR-5560 (NRC – Hashemian)	KKB 555D0220	Ageing mechanism Failure statistic Results of test	
C 2	A Review of Equipment Ageing Theory and Technology	EPRI NP-1558 Project 890-1	KKB / Bibliothek EI 42	Ageing of material and components	
C 3	Equipment qualification reference manual	EPRI / Holzmann (Handbuch)	KKB / KBE-Q	Summary of ageing data	
C 4	The effects of radiation on electronic devices and circuits	Kerntechnik 55, Nr. 5, 1990	KKB / KBE-Q 402D0014 Band 2		1
C 5	Steckbrief Funktionseinheiten, Teil 1	M 004/1	KKB / KBE-Q Ordner Steck-brief-Originale	Ageing mechanism	1
C 6	Untersuchung zur Alterung bzw. der Lebensdauer von elektrischen Einrichtungen des Sicherheitssystems und der Störfallinstrumentierung in kerntechnischen Anlagen unter betrieblichen Einflüssen (Alster)	93-0721 TÜV-Norddeutsch-land e.V. (Abschlussbericht vom 2. April 1992 zum BMU-Forschungsvor-haben SR 441)	KKG-E Ordner 258 KKB 555D0220	Ageing, life time of electrical components of safety system and accident instrumentation	1 1

GSKL – Fachteam AÜP E – Technik	REVIEW OF AGEING MANAGEMENT Equipment: Pressure Transmitter	Number: **X 001/2** Plant spec. ID No. Page 1 of 3	Rev.

P A R T 2 : P O S S I B L E D I A G N O S T I C M E T H O D S

_E X A M P L E_

L I S T O F C O N T E N T S

Equipment Information

Equipment:

Pressure Transmitter

REMARKS:

PART 1: AGEING MECHANISM see file No.: X 001/1

DISTRIBUTION: KKB: Electrical Department KKG: Electrical Department
KKL: Electrical Department KKM: Electrical Department

Revision:

1) Add information according BP-092-EQ99001 chapter 3.1 | 1

	Name	Date	Rev. No.	1					
			Date	20.05.99					
Written by	sig. gf	12.12.94	Written by	sig. FD					
Checked by	sig. th	12.12.94	Checked by	sig. bgy					

GSKL - Fachteam AÜP E - Technik	REVIEW OF AGEING MANAGEMENT Equipment: Pressure Transmitter	Number: **X 001/2** Plant spec. ID No. Page 2 of 3	Rev.

D: Diagnostic method for detection of ageing

EXAMPLE

Equipment, Part	Ageing mechanism	Diagnostic method	Ref.	Statement / Remarks	Rev.
Electronic board with parts	Corrosion, Oxidation Chemical Effects Loosening of Conductor Embrittlement Change of electrical property	Recording of characte-ristic, hysteresis and trend, Visual check	E 3		1 1 1
Soldered joint	Oxidation Corrosion	Visual check	E 3		1
Plug-in contact, clamping connection	Corrosion, Oxidation Wear	Visual check			
Potentiometer	Oxidation Corrosion Erosion Wear	Visual check Test of continuity	E 3 E 1		1
Cover seal	Deformation Embrittlement Hardening Cracking	Visual check		*preventive replace if necessary*	
Cable connection with penetration	Corrosion Oxidation Embrittlement	Visual check			
Pressure-cell	Tightness, leakage of oil Fatigue Wear Corrosion	Visual check Recording of characte-ristic, hysteresis and trend,	E 2		
Measure-pipe with screwed gland	Tightness Corrosion Fatigue Loosing of Fittings	Cleaning, flush and vent Visual check		pipe locked	1
Valves	Tightness Wear Corrosion Fatigue	Cleaning, flush and vent Visual check		valve locked	

GSKL - Fachteam AÜP E - Technik	REVIEW OF AGEING MANAGEMENT Equipment: Pressure Transmitter	Number: **X 001/2** Plant spec. ID No. Page 3 of 3	Rev.

E: Documentation / Reference to Diagnostic method — ***E X A M P L E***

Ref.	Title	Number	Place of deposit at plant	Info-Contents	Rev.
E 1	On-Line Calibration Testing Techniques	NUREG/CR-5903 (NRC – Hashemian)	KKB 555D0220	Testing method	
E 2	On-Line Detection of Oil Loss in Rosemount Transmitters	NUREG/CR-5851 (NRC-Hashemian) Rosemount Bulletin No. 4	KKB 555D0220	Testing method	
E 3	Steckbrief Funktionseinheiten, Teil 2	M 004/2	KKB / KBE-Q Ordner Steck-brief-Originale	Diagnostic method	1

NOK KKB	REVIEW of AGEING MANAGEMENT **Equipment:** **Transmitter inside Containment**	Plant spec. ID No. ***EXAMPLE XXX*** Number: *X 001*/3 Page 1 of 11	Rev.

P A R T 3 : P L A N T S P E C I F I C R E V I E W N P P B e z n a u

F: Comparison Ageing with Maintenance
G: List of gaps
H: Measure to fill the gaps
K: Documentation/Reference for plant specific review
L: List of concerned Equipments in the plant
M: Utilisation time and verification of qualification

Equipment information

Equipment: **Transmitter**

Type: Rosemount 1154 Series H
Rosemount 1154 Series P

Manufacturer: Rosemount Supplier: Rosemount

REMARKS:

PART 1: AGEING MECHANISM see file No.: *X 001*/1
PART 2: POSSIBLE DIAGNOSTIC METHODS see file No.: *X 001*/2

DISTRIBUTION: KBE (Electrical departement) KBE-Q (QA)

Revision:

1) Page 4 and 5: added WPs for preventive replacing of transmitter-electronic board (K 16 and K 17)
2) Page 5: added reference K 18

	Name	Date	Rev. No.	1	2				
			Date	18.09.98	29.01.99				
Written by	S. Jevsenak	18.08.95	Written by	sig. jev	sig. jev				
Checked by	K. Thoma	01.09.95	Checked by	sig. th	sig. th				

N O K K K B	REVIEW of AGEING MANAGEMENT **Equipment:** **Transmitter inside Containment**	Plant spec. ID No. *EXAMPLE XXX* Number: *X 001*/3 Page 2 of 11	Rev.

F: Comparison Ageing with Maintenance

Equipment, Part	AGEING mechanism [from file Part 1]	Diagnostic method / *Remarks* [from file Part 2]	R	Integrated into maintenance YES	NO	Ref.
Electronic board with parts	Corrosion, Oxidation Chemical Effects Loosening of Conductor Embrittlement Change of electrical property	Record of characteristic, hysteresis and trend Visual check		X X		K 1 K 2 K 3
Soldered joint	Oxidation Corrosion	Visual check		X	G 1	
Plug-in contact, clamping connection	Corrosion, Oxidation Wear	Visual check		X	G 1	
Potentiometer	Oxidation Corrosion Erosion Wear	Visual check Test of continuity	E 1	X	G 1	K 3
Cover seal	Deformation Embrittlement Hardening Cracking	Visual check		X	G 3	
Cable connection with penetration	Corrosion Oxidation Embrittlement	Visual check		X	G 1	
Pressure-cell	Tightness Fatigue Wear Corrosion	Visual check Record of characteristic, hysteresis and trend	E 2	X		K 1 K 2 K 3
Measure-pipe with screwed gland	Tightness Corrosion Fatigue Loosing of Fittings	Cleaning, flush and vent Visual check		X	G 2	
Valves	Tightness Wear Corrosion Fatigue	Cleaning, flush and vent Visual check		X	G 2	

G: List of gaps

G1) Visual check of soldering connection, plug-in contact, clamping connection, potentiometer and cable connection with penetration is not mentioned in maintenance procedure.

G2) Visual check of pipes with screwed gland and valves are missing in the maintenance procedure.

G3) Preventive replacement of cover seal is missing in the maintenance procedures.

N O K K K B	REVIEW of AGEING MANAGEMENT **Equipment:** **Transmitter inside Containment**	Plant spec. ID No. *EXAMPLE XXX*	Rev
		Number: *X 001*/3	

H: Measure to fill the gaps (according to G)

	Action executed		
	Rev	Date	Signature
to G1) G2) G3)			
Add it in the following maintenance procedures:			
WP-E-I88005 for Unit 1	5	31.08.95	sig. gei
WP-E-I88006 for Unit 2	2	31.08.95	sig. gei
only for Class 1E transmitter inside containment			
Preventive replace of electronic board (according M3)			
After 22 years replacement, add it in the maintenance procedure.	0	03.10.95	sig. gei
Preventive replace of transmitter (according M3)			
34 years interval add it in “Ageing Management File”			

K: Documentation / Reference for the plant specific review

Ref.	Title	Number with Rev.*)	Place of deposit at plant	Info-Contents	Rev
K 1	Transmitter der Gruppe B (I) Transmitter der Gruppe B (II)	WP-E-I88005 Rev. 4 WP-E-I88006 Rev. 1	KBE-X KBE-X	Time-Intervals for maintenance works	
K 2	Abgleich von Druck- und Differenzdruck Transmittern	AV-E-I94001 Rev. 0	KBE-X	Manual for calibration of transmitters	
K 3	Manual, Pressure Transmitter	KKB 555 D0168	Archiv	Description of calibration, Maintenance	
K 4	Qualification report for pressure transmitter Modell 1154 Modell 1154 H	Rosemount report D8400102 Rev. B D8700096 Rev. H	Archiv KKB 555 D162 KKB 541 D0105	 Qualification test Qualification test	
K 5	Testprofile LOCA-Tests für Material, dass in 1E klassiert. Anlageteilen innerhalb des Containments eingesetzt wird	TM-402-02/2002 R. 2	KBE-X	LOCA Test-Profile	
K 6	Seismische Requalifikation Kernkraftwerke Beznau I+II	TM-KKB 581/54 R. 0	KBE-Q	Floor-response Spectres	
K 7	Anschluss Bericht	ICS /91/526	KBE-Q		
K 8	Anschluss Prüfprogramm	TD 1378	KBE-Q		
K 9	Alterungsüberwachung von Transmittern	AN-402-EI93005	KBE-X	Ageing mechanism	
K 10	Vorbeugender Austausch der Transmitter-Elektronikkarte	WP-E-I95003 Rev. 0	KBE-X	Interval for replacement of Electronic-Card, Un. 1	1
K 11	Vorbeugender Austausch der Transmitter-Elektronikkarte	WP-E-I95004 Rev. 0	KBE-X	Interval for replacement of Electronic-Card, Un. 2	1
K 12	Rosemount-Transmitter Qualifikationstest, Abklärung Einfluss der Genauigkeitsänd.	AN-402-EQ98036 Rev.0	KBE-X	Influence from radiation to SPAN and URL	2

*) Rev. index who was actual during the situation analysis of chapter F

L: List of concerned Equipments in the NPP Beznau

Unit 1:

L1: List of concerned Equipments (TP-Numbers)
- Transmitter inside containment Unit 1

Unit 2:

L2: List of concerned Equipments (TP-Numbers)
- Transmitter inside containment Unit 2

Review of Ageing Management

EXAMPLE
List L1 (L2)

NOK - KKB
Unit 1

AN-402-EQ94001 S-AÜP: Transmitter inside Containment

Equip.N°	Name of Equip.	Serialnr	Manufacturer	Type	in Operation	Techn.Place		Room		QG	SK	Qual.
505806	TRANSMITTER	0504786	ROSEMOUNT	1154-HP5	01.04.1993	10JRC FT 0415	TRANSMITTER DURCHFLUSS LOOP A	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505805	TRANSMITTER	0504787	ROSEMOUNT	1154-HP5	01.04.1993	10JRC FT 0416	TRANSMITTER DURCHFLUSS LOOP A	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505804	TRANSMITTER	0504799	ROSEMOUNT	1154-HP5	01.04.1993	10JRC FT 0417	TRANSMITTER DURCHFLUSS LOOP A	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505803	TRANSMITTER	0504800	ROSEMOUNT	1154-HP5	01.04.1993	10JRC FT 0425	TRANSMITTER DURCHFLUSS LOOP B	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505802	TRANSMITTER	0504801	ROSEMOUNT	1154-HP5	01.04.1993	10JRC FT 0426	TRANSMITTER DURCHFLUSS LOOP B	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505807	TRANSMITTER	0503218	ROSEMOUNT	1154-HP5	01.04.1993	10JRC FT 0427	TRANSMITTER DURCHFLUSS LOOP B	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505759	TRANSMITTER	0504776	ROSEMOUNT	1154-HP5	01.04.1993	10JRC LT 0459	TRANSMITTER NIVEAU DRUCKHALTER	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505758	TRANSMITTER	0504777	ROSEMOUNT	1154-HP5	01.04.1993	10JRC LT 0460	TRANSMITTER NIVEAU DRUCKHALTER	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505757	TRANSMITTER	0504780	ROSEMOUNT	1154-HP5	01.04.1993	10JRC LT 0461	TRANSMITTER NIVEAU DRUCKHALTER	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505755	TRANSMITTER	0504781	ROSEMOUNT	1154-HP5	01.04.1993	10JRC LT 0462	TRANSMITTER NIVEAU DRUCKHALTER	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505777	TRANSMITTER	0504491	ROSEMOUNT	1154-DP4	01.04.1993	10JRC LT 0480	TRANSMITTER NIVEAU DE-A	1S501	BEDIENUNGSBODEN KOTE 340.00	A	1E	VOLL
505776	TRANSMITTER	0504492	ROSEMOUNT	1154-DP4	01.04.1993	10JRC LT 0481	TRANSMITTER NIVEAU DE-A	1S501	BEDIENUNGSBODEN KOTE 340.00	A	1E	VOLL
505775	TRANSMITTER	0504493	ROSEMOUNT	1154-DP4	01.04.1993	10JRC LT 0482	TRANSMITTER NIVEAU DE-A	1S501	BEDIENUNGSBODEN KOTE 340.00	A	1E	VOLL
505687	TRANSMITTER	0504788	ROSEMOUNT	1154-DP5	01.04.1993	10JRC LT 0483	TRANSMITTER NIVEAU DE-A	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505774	TRANSMITTER	0504610	ROSEMOUNT	1154-DP4	01.04.1993	10JRC LT 0490	TRANSMITTER NIVEAU DE-B	1S501	BEDIENUNGSBODEN KOTE 340.00	A	1E	VOLL
505771	TRANSMITTER	0504628	ROSEMOUNT	1154-DP4	01.04.1993	10JRC LT 0491	TRANSMITTER NIVEAU DE-B	1S501	BEDIENUNGSBODEN KOTE 340.00	A	1E	VOLL
505770	TRANSMITTER	0504629	ROSEMOUNT	1154-DP4	01.04.1993	10JRC LT 0492	TRANSMITTER NIVEAU DE-B	1S501	BEDIENUNGSBODEN KOTE 340.00	A	1E	VOLL
505686	TRANSMITTER	0504789	ROSEMOUNT	1154-DP5	01.04.1993	10JRC LT 0493	TRANSMITTER NIVEAU DE-B	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505697	TRANSMITTER	0504960	ROSEMOUNT	1154-SH9	01.04.1993	10JRC PT 0457	TRANSMITTER DRUCK DRUCKHALTER	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505696	TRANSMITTER	0504980	ROSEMOUNT	1154-SH9	01.04.1993	10JRC PT 0458	TRANSMITTER DRUCK DRUCKHALTER	1S201	VENTILBODEN KOTE 323.80	A	1E	VOLL
505744	TRANSMITTER	0504497	ROSEMOUNT	1154-DP7	01.04.1993	10JSI FT 0923	TRANSMITTER DURCHFLUSS	1S203	RAUM ABLASSNACHKÜHLER	A	1E	VOLL
505798	TRANSMITTER		ROSEMOUNT	1154-DP5	01.04.1993	10PRW FT 5513	TRANSMITTER DURCHFLUSS 10SHV	1S501	BEDIENUNGSBODEN KOTE 340.00	A	1E	VOLL
505800	TRANSMITTER		ROSEMOUNT	1154-DP5	01.04.1993	10PRW FT 5514	TRANSMITTER DURCHFLUSS 10SHV	1S501	BEDIENUNGSBODEN KOTE 340.00	A	1E	VOLL

Donnerstag, 31. Oktober 2002

M: Utilisation time and verification of qualification

M1: Comparison Type test - requirements

Test steps	Test parameters	Ref.	Test parameters	Ref.	Requirement in NPP Beznau	Ref
Type	1154		1154 H			
M1.1: PRE-AGEING						
Temperature ϑ	98 °C	K 4	98 °C	K 4		
Time t	45 + 90 days		45 + 90 days			
Radiation γ	55 Mrad		55 Mrad		3.5 Mrad (life dose)	
Dose rate 2 h	2 Mrad/h	K 4	2.07 Mrad/h	K 4		
4 h	1.5 Mrad/h		1.5 Mrad/h			
45.5 h	1 Mrad/h		1.2 Mrad/h			
Activation energy e_a	0.78 eV	K 4	0.78 eV	K 4		
M1.2: LOCA						
Temperature ϑ	max. 215 °C	K 4	max. 215 °C	K 4	calculated	K 5
Pressure p	max. 7.6 barg	K 3	max. 5.8 barg	K 3	plant condition	
relative humidity f_{rel}	100% Spray		100% Spray		TM-402-02/2002	
Test profile No.	Rosemount D8400102 equivalent to	K 4	Rosemount D8700096	K 4	app. 7.4, envelope curve B, F = D	
Post-LOCA	1 year at 49 °C	K 4	9 days at 98 °C	K 4		
additional to Post-LOCA						
Radiation, γ	55 Mrad	K 4	55 Mrad	K 4		
Dose rate	1 Mrad/h		1 Mrad/h			
Total Radiation γ	55+55=110 Mrad	K 4	55+55=110 Mrad	K 4	74 Mrad (TID)	K 5
M1.3: Seismic	hor ver		hor ver		FRS/$_{\text{SSE, altitude 340}}$	
Acceleration a	7 g 4.2 g (ZPA)	K 4	8.5 g 5.2 g (ZPA)	K 4	$\hat{a}_{/D=2\%}$ = 1.6 g	K 6
Resonance frequency f_0	> 100 Hz		> 100 Hz			
M1.4: Qualified life (manufacturer info)	10 years at 49 °C	K 4	10 years at 49 °C	K 4		
with replacing electronic board after 10 years in operation at 49 °C ambient temperature	15 years at 49 °C	K 4	15 years at 49 °C	K 4		

M1a: Electrical connection see page 10

More information see page 9

	Ref.	Rev
to M1.1		
a) γ		
max. operating dose for 40 years according Plant-Handbook (June 95) (γ = 100 mSv/h)		
$\gamma/_{40\ year}$ = 40 * 365 * 24 * 100 mSv/h = 35 kSv (3.5 Mrad)		
$\gamma/_{test}$ = 55 Mrad (see M1.2)	K 4	
Margin = 55 Mrad – 3.5 Mrad = **51.5 Mrad**		
b) Pre ageing, ϑ, Qualified Life		
Ea = 0.78 eV	K 4	
<u>Electronic board</u>:		
10 years / $_{49\ °C}$	K 4	
at 40 °C : $t_1 = t_2 * e^{((Ea/k)*(1/T1-1/T2))}$ = 10 years * $e^{((0.78/0.00008617)*(1/313 - 1/322))}$ = **t_1 = 22.67 years**		
<u>Transmitter</u>:		
15 years / $_{49\ °C}$ (from test: t_2 = 45+90 days T2 = 98 + 273 = 371 K)	K 4	
at 40 °C : $t_1 = t_2 * e^{((Ea/k)*(1/T1-1/T2))}$ = 135 days * $e^{((0.78/0.00008617)*(1/313 - 1/371))}$ = **t_1 = 34 years**		
<u>Conclusion</u>:		
Transmitter has a expected life of 34 years at 40 °C ambient temperature (with replacing electronic board after 22 years).		

	Ref.	Rev
M1a) Electrical connection Cable is sealed with metal sleeve. The basic design was qualified by Westinghouse during project NANO. **The expected life is not shorter than for cable.**		

N O K K K B	REVIEW of AGEING MANAGEMENT Equipment: Transmitter inside Containment	Plant spec. ID No. ***EXAMPLE XXX***	Rev.
		Number: *X 001*/3	
		Page 11 of 11	

M: Utilisation time and verification of qualification

M2: Qualification margin	Ref.
The electronic board has a qualified life from **22.67 years** at 40 °C ambient temperature. The transmitter **without E-board** has a qualified life from **34 years.**	
Detailed information see chapter M1.1 / M1.2 / M1.3 / M1.4	

M3: Utilisation time

Based on M2:

replace the electronic board	t ≤ 22 years	add data into WP-management file
replace the whole transmitter	t ≤ 34 years	add data into Ageing-management file

Detailed information see page 9

ANNEX B

SUPPLEMENTARY INFORMATION ON CURRENT INDUSTRY PRACTICES

This annex includes short write-ups on a number of subjects related to the issues of this TECDOC. These write-ups are given in the following six sections of the annex. The material in these short sections were provided by members of the committee. They have been included here unedited and unverified. As such, this information is to be viewed for information only.

B.1. Specific Examples of R&D Projects with Regard to I&C Component Ageing

B.2. Qualification of a Smart Transmitter for Nuclear Safety Applications

B.3. Manageing the Lifetime of Control Rod Drives in the PAKS NPP

B.4. Developing an Ageing-Management Project in the Kozluduy NPP

B.5. Examples of the Application of Screening Criteria

B.6. Examples of Typical Stressors and Ageing Effects for Cables

ANNEX B.1.

SPECIFIC EXAMPLES OF R&D PROJECTS RELATED TO I&C COMPONENT AGEING

B.1.1. Artificial vs. Natural Ageing of Electrical Components

A project has been initiated at EPRI to provide long term in-plant data for comparing the effects of natural vs. artificial ageing of various types of electrical equipment. Material property tests on specimens placed in nine operating reactors are providing data on the long term natural ageing effects of plant environments on cabling and other electrical components. Specifically, this project was designed to look for differences between the ageing processes in the containment environment and those occurring during accelerated testing as used for qualification of electrical components. This project is one of the very few data sources providing information intended to confirm the validity of the activation energy as used for equipment qualification purposes. This project is to provide utilities with the necessary information for avoiding the need for additional equipment qualification requirements.

B.1.2. Cable Condition Monitoring Methods

Cable CM and assessment methods have been developed in a number of countries for in-plant implementation. This product is of value to utilities for resolving cable condition assessment issues and by reducing long term maintenance costs for cable systems. A programme at EPRI is concerned with cable CM, assessment and troubleshooting. An assessment of various diagnostic tools for cable condition evaluation will be performed and published as an EPRI guideline. A method for detecting local insulation damage for unshielded low-voltage cable will be evaluated for in-plant use.

- Several cable-ageing methods have been developed which are expected to have a significant impact to resolution of cable ageing issues.
- First proof-of-principle experiments using the newly conceived wear-out approach show that it offers unique capabilities for predicting the remaining lifetimes of nuclear power plant cable materials.
- Early results show that two new CM techniques based on modulus profiling and nuclear magnetic resonance measurements may be among the best CM techniques available for determining cable condition in existing nuclear power plants.
- Research has begun on low-voltage integrated cable ageing management and for assessing the state of the industry and CM techniques for medium voltage cables.

ANNEX B.2.

QUALIFICATION OF A SMART TRANSMITTER FOR NUCLEAR SAFETY APPLICATIONS

The qualification of selected smart transmitters, performing the qualification testing and evaluation activities has been completed based on the EPRI TR-106439 and EPRI TR-107339 guidelines. This has saved utilities and equipment suppliers from individually repeating the tasks for each application, and enhanced regulatory acceptance.

- To demonstrate the qualification methodology developed by EPRI and approved by the NRC for commercial-grade digital equipment, a smart transmitter from Rosemount was selected for evaluation and qualification. As a result, the Rosemount 3051C smart transmitter was successfully qualified and is now available as a 1E device from Rosemount for utility use. *(Generic Qualification of the Rosemount 3051 N Pressure Transmitter, EPRI 1001468.*) The smart transmitter qualification task was based on generic qualification activities previously developed by EPRI as described in EPRI TR-106439, *Guideline on Evaluation and Acceptance of Commercial Grade Digital Equipment for Nuclear Safety Applications*, and EPRI TR-107339, *Evaluating Commercial Digital Equipment for High Integrity Applications*.
- Documentation of the tests and evaluations has been completed and a lessons learned report has also been published.

This qualification will allow replacement of old 1150 series analog pressure transmitters, which are based on an early 1970’s design, that are widely used in safety related applications. Current requirements for analog transmitter calibration range from 3 months to 2 years. The manufacturer indicates that the new sensors should be calibrated every 10 years, a reduction in calibration frequency of a factor of five or more. Also some calibrations currently require four people for monitoring, and also require access to the sensor. The new sensors can use remote checks of their electronics from the control room, saving time, manpower, and radiation exposure. The new transmitter will provide a more accurate, more stable, and more capable replacement for the analog pressure transmitters.

ANNEX B.3.

MANAGEING THE LIFETIME OF CONTROL ROD DRIVES IN THE PAKS NPP

The control rod drives regulating reactor power are equipment of primary importance. Accordingly, they were designed with a multiplied safety factor, and they were licensed on the basis of conservative considerations. As a result of this approach, their allowed life-time was originally limited to 5 years, limiting — at the same time — the allowed number of events for different operational occurrences. The reliable, event free operation of the reactors on one hand, as well as the use of local CM techniques on the other hand initiated the idea of a new approach to design life identification.

The lifetime extension programme was elaborated by the original manufacturer, ŠKODA in the Czech Republic, while its application was approved and is inspected by the Nuclear Safety Directorate of the Hungarian Atomic Energy Authority.

Based on the programme, the drives undergo a full-scope diagnostic inspection during every annual outage of the reactor (this is called Revision No.1 of the drives). Following 6 years of operation, condition inspection is carried out with partial or full disassembling of the drives (called Revision No. 2 and 3). If needed, a partial renewal takes place in these revisions, using of spare parts. Should a Level 1. or 2. revision reveal the non-fulfillment of any criteria, an extraordinary revision at one level higher is carried out. A revelation of a non-compliance in the third level revision can lead to an extraordinary replacement of the whole drive.

In order to cover an even broader range of degradations (any material or structural defects), after the 10th year of operation, a full scope destructive investigation of one of the drives has already been executed, and this practice is to be followed in the future as well. Based on the experiences gathered so far, a hypothesis can be set that the drives will have to be replaced after the 18th operational cycle. Due to fact that drives cannot be used in the same year when Revision No. 2 or 3 takes place, the 18 cycles result in a 23-year-long practical life-cycle.

The lifetime extension described above provides the chance to decrease the yearly power generation cost very significantly.

ANNEX B.4.

DEVELOPING AN AGEING-MANAGEMENT PROGRAMME IN THE KOZLUDUY NPP

A custom-tailored ageing management programme is an important activity as it contributes towards maintaining plant safety at a high level over the plant's entire design service life. At the same time, one may expect economic advantages resulting from higher reliability and availability. With this in mind, a special programme was jointly developed by experts from Kozloduy and Framatome ANP and is being implemented by a consortium formed of Framatome ANP and the Russian company, Atomstroyexport. The primary goals of the programme are to:

- perform an independent assessment of the remaining service life of plant components, systems and structures that conforms to international experts' acceptance criteria,
- identify the need for further investigations or analyses in certain cases,
- find solutions for improving safety that are economical at the same time.

The ageing-management programme is part of a comprehensive back fitting project for Units 3 and 4 of the Kozloduy plant and comprises three phases:

- In the first phase, the remaining service life of representative components, systems and structures (relevant to safety and availability) is determined at both plant units, using state of the art techniques.
- In the second phase, a computerized system is developed to handle all relevant component and system data — both original construction data and data recorded during plant operation (e.g. loads and environmental conditions) — as well as information obtained from in-service inspections and replacement activities.
- In the final phase, an ageing-management programme is generated to detect, evaluate and mitigate relevant ageing degradation mechanisms and to identify locations in the plant where they are likely to occur.

ANNEX B.5.

APPLICATION OF SCREENING CRITERIA FOR INSULATED CABLES AND CONNECTIONS

The function of insulated cables and connections is to electrically connect specified sections of an electrical circuit to deliver voltage, current or signals. Electrical cables and their required terminations (i.e. connections) are reviewed as a single component commodity group. The types of connections included in this review are splices, connectors, and terminal blocks. Numerous insulated cables and connections are included in the EQ Programme. The insulated cables and connections that are included in this programme have a qualified life that is documented in the EQ Programme. Components in the EQ Programme that have a qualified life of less than 40 years are replaced on the basis of a specified time period at the end of their qualified life. Components in the EQ Programme that have a qualified life based on the 40-year current operating license term are the subject of Time-Limited Ageing Analysis. Accordingly, all insulated cables and connections within the EQ Programme are exempt from screening under 10 CFR 54.21(a)(1)(ii) and are not subject to an ageing management review.

Insulated cables and connections that perform an intended function within the scope of license renewal, but are not included in the EQ Programme, meet the criterion of 10 CFR 54.21(a)(1)(ii) and are subject to an ageing management review.

An example listing of electrical/I&C component commodity groups subject to ageing management review, their intended functions, and reference to the ageing management results is provided in tabular form below.

ELECTRICAL/I&C COMPONENT COMMODITY GROUPS FOR IN-SCOPE SYSTEMS AND STRUCTURES AT RNP			
Alarm Units	Electrical/I&C Penetration Assemblies	Loop Controllers	Signal Conditioners
Analyzers	Elements	Meters	Solenoid Operators
Annunciators	Fuses	Motor Control Centers	Solid-State Devices
Batteries	Generators	Motors	Splices
Bus Duct	Heat Tracing	Power Distribution Panels	Surge Arresters
Chargers	Heaters	Power Supplies	Switches
Circuit Breakers	Indicators	Radiation Monitors	Switchgear
Converters	Insulated Cables and Connections	Recorders	Terminal Blocks
Communication Equipment	Inverters	Regulators	Thermocouples
Electrical Controls and Panel Internal Component Assemblies	Isolators	Relays	Transducers
	Light Bulbs	RTDs	Transformers
	Load Centers	Sensors	

Table B5. Examples of Electrical/I&C Component Commodity Groups.

ANNEX B.6.

EXAMPLES OF TYPICAL STRESSORS AND AGEING EFFECTS FOR CABLES

In the ageing management review of cable components the following stressors and ageing effects, as typical examples, may be identified:

Applicable Stressor	Voltage Category	Applicability	Potential Ageing Effects
Heat	Low & Medium	All insulation materials	Reduced insulation resistance (IR); electrical failure; hardening; embrittlement; cracking; discoloration
Radiation and oxygen	Low & Medium	All insulation materials	Reduced IR; electrical failure; hardening; embrittlement; cracking; discoloration
Moisture	Low & Medium	All insulation materials, contact surfaces	Reduced IR (for ageing cable); corrosion and oxidation of metals
Moisture and voltage stress	Medium	All insulation materials exposed to standing water	Electrical failure (caused by a breakdown of the insulation)
External mechanical stresses	Low & Medium	All insulation materials	Wear or low-cycle fatigue

Table B6. Typical Stressors and Ageing Effects for Cables.

ANNEX C

COUNTRY REPORTS

This annex contains country reports as listed below. These country reports were included here in alphabetical order and as received for the countries listed.

Annex	Country	Title
C.1.	France	Ageing Management for I&C on French NPP
C.2.	Hungary	I&C Ageing Management in the PAKS NPP
C.3.	Japan	Current Status of Cable Ageing Management and Research in Japan
C.4.	Republic of Korea	Country Report on Plant Life Cycle and Ageing Management in the Republic of Korea
C.5.	Russian Federation	Experience in Management of Equipment Service Life in Russian Nuclear Power Plants
C.6.	Switzerland	Replacement of the Reactor Control and Protection System in Unit 1 & 2 of the Beznau Nuclear Power Plant
C.7.	United States of America	I&C Ageing Management in U.S. Nuclear Power Plants

ANNEX C.1.

AGEING MANAGEMENT FOR I&C ON FRENCH NPP

S. Manners
IRSN, France

1. ABSTRACT

The French operator, Electricité de France, has undertaken various actions to anticipate ageing and obsolescence of the instrumentation and control (I&C) installed on its nuclear power plant (NPP). The French Safety Authority (DGSNR) and its independent assessors at the "Institute de Radioprotection et de Sûreté Nucléaire" (IRSN) have been kept informed and have followed in particular the actions affecting the safety and safety related systems. Recently, in preparation for the 20 and 30 year NPP formal safety reviews, the operator's overall approach for ageing management and the safety demonstration aspects have been the subject of a specific examination by the Safety Authority and its assessor. This paper gives a general overview of the issues dealt with and the ongoing actions concerning the I&C.

2. CONTEXT AND WHAT IS AT STAKE FOR I&C AGEING ISSUES

2.1. Overview of I&C Type and Age in French PWRs

France has a unique operator, Electricité de France, for all its electrical power generation, transmission and distribution. Electricité de France's current nuclear generating capacity consists of 58 pressurized water reactors which can be categorized into 3 basic design series (CP, P4, N4) that have been progressively put into operation between 1978 and 1997.

The I&C technology used on each reactor series type has evolved with the plant series design. As well as a diverse range of instrumentation, actuators, electrical relay equipment and discrete controllers, one can identify a dozen or so 'I&C integrated systems' including digital programmable controllers, computer systems and modular analogue controllers which are standardized for the different NPP design series and have with key roles for the process control and safety systems.

The earliest CP series is a 900MWe PWR power plant built in 1970's and 80's. It uses mainly electromagnetic relays and analogue electronics in its I&C for safety and control functions. There are a total of 34 reactors on 9 sites. Recently some parts of the reactor protection system and control systems have been back fitted with modern digital I&C on the first generation plants of this series (6 NPPs).

The subsequent P4 series 1300MWe power plant built in 1980's uses the digital programmable I&C technologies of the era for both safety and process control functions, with some analogue electronic process control equipment existing on earlier plants. There are a total of 20 reactors on 8 sites.

The most recent N4 1450MWe reactor series was equipped during the 1990's. 4 reactors have been in operational service at 2 sites (Civaux and Chooz B) since 1996-7. The plant uses digital I&C for practically all process control and safety protection. The operator interface in the main control room is fully computerized and multiplexed data communications networks are used extensively. The instrumentation however remains similar to that used on the older series (as yet no fieldbus or widespread use of smart sensors).

2.2. Economic Stakes

If, during a NPP's lifetime, the original I&C proves impossible to maintain, a renovation of I&C functions with the implementation of new hardware has to be envisaged. The economic stakes are significant; the complete I&C renovation for a NPP being estimated at many tens of millions of Euros. Furthermore, a complete renovation presents significant technical and economic risks compared to those linked to the continuation of a strategy of adapted maintenance of the existing I&C.

2.3. Operating Experience Feedback

To date Electricité de France considers the operational reliability of the I&C to be highly satisfactory. The failure rates ascertained under real plant operational conditions are most often very much inferior to those estimated for the probabilistic safety studies and, have been stable for many years. In fact I&C failures have a very small impact on the total availability of Electricité de France's generating capacity.

Despite these good overall results, a few equipment subgroups, in particular computer peripherals, are affected by failures which have been judged too numerous by Electricité de France. These are the object of replacement studies.

3. DISCUSSION OF I&C AGEING ISSUES RAISED BY SAFETY ASSESSOR AND PLANT OPERATOR

The following paragraph discusses briefly some of the ageing issues applicable to I&C that have been raised by the safety assessor and the plant operator in France as elsewhere. There has been some deliberation over what defines exactly the 'ageing' of NPP equipment in general and how this should be treated with respect to the safety demonstration. The I&C equipment has its own set of particularities. Nonetheless, I&C has been examined within the context of a general ageing management methodology applicable for all NPP structures, systems and components.

3.1. I&C Ageing Mechanisms and Effects

Wear-out and random failure of components are taken into account in the initial design of the I&C systems; all the safety and much of the non safety I&C is redundant and of fail safe design. Statutory periodic testing and technical specifications for NPP operation ensure adequate availability of the reactor safety functions. The initial safety qualification includes accelerated ageing testing to guarantee that I&C components will function as required at the end of their service life.

This approach assumes that the I&C retains a constant failure rate and that the initial hypothesis established at the design stages and used for the qualification testing remain valid for the service life of the equipment. It is thus necessary to analyze the in-service operating conditions with respect to specifications and verify that the appropriate maintenance is carried out during the equipment lifetime.

Many I&C components are already known to be subject to physical degradation with time and operation. Specific 'ageing mechanisms' have been identified which may or may not be taken account of in the equipment design specification or in the operating and maintenance procedures. Premature 'ageing' may lead to the reduced reliability of equipment in normal operating conditions (increased failure rate) and could theoretically effect equipment qualification for accident conditions. Such effects need to be identified. As the age of the NPP installations is extending the operating life of many I&C components into 'uncharted territory' (i.e. where no other real operating experience exists), the concern is that other, unforeseen, ageing mechanisms may manifest themselves. Thus all potential mechanisms and effects have to be considered in the ageing assessment.

3.2. Obsolescence

It is also important to consider the means for continued support for routine maintenance (repair and failed parts replacement) and also the capacity of the original system to meet future plant needs (implementation of functional modifications or other changes to requirements). Here we are dealing with not only availability of spare components, but also human resources and expertise, documented knowledge, design and development tools, etc.. This applies, not only to the plant operator, but also notably to the I&C equipment supplier market. In fact, obsolescence of equipment and resources would appear to be the dominant factors to be addressed for assuring the continued service lifetime of the initially installed I&C systems.

Whilst, it can be claimed that evolutions in the technology and the architecture of the I&C have made possible improvements to availability, operating margins and safety. The task of maintaining the I&C operational over the long term of a NPP lifetime is increasingly sensitive to the rapidly changing electronic component market, evolutions in software engineering, support from equipment manufacturers and availability of competences for legacy systems.

3.3. Ageing and Obsolescence Assessment

Hence, it can be seen that the management of ageing and obsolescence of the I&C involves the evaluation of many interacting issues relevant to long term NPP operating strategies. To maintain the required targets for plant availability and preserve the plant safety over the different options for NPP operating lifetime, the evolution of functional needs, material performances, component supply and human resources has to be predicted. Choices between maintaining or modernizing I&C have to be made.

Whatever the strategy chosen by the operator, for the Safety Authority the aim is to ensure that all safety aspects are adequately treated. This includes, in a strategy opting for no modernization of the I&C, the consideration of potential risks. This will require further research into possible ageing mechanisms and their effects together with the analysis of postulated situations resulting from ageing effects or obsolescence. When the option is for modernization of the I&C, a specific licensing process has to be engaged. This must treat the particularities of a design for partial modernization (interfacing, etc.), the special back-fitting operations (scheduling installation work packets, etc.) and the qualification of modern digital programmable I&C equipment (software requirements, etc.).

Whilst evidently considering safety at the forefront, the plant operators' strategies for the management ageing and obsolescence will necessarily be oriented to evaluate the industrial and economic risk as well. When taking into account the number of variables in an analysis for all plant equipment — relating ageing mechanisms, potential effects, obsolescence, human resources, modifications, etc., together with the operators industrial and economic strategy options concerning plant operating lifetime — the scope of a safety assessment (even just for I&C) can be very large.

4. FRENCH SAFETY AUTHORITY ACTIONS CONCERNING AGEING AND PLANT LIFE

4.1. Plant Lifetime

France's existing NPPs were initially designed with an overall objective for 40-year operating life expectancy. Extension of one or two decades is currently being considered in the operators' strategy. In the French regulations for licensing of a NPP there are no statutory life times stipulated which are directly applicable to the I&C components. 'Ageing assessment', 'plant life management' and 'plant life extension' are matters for the statutory continuous surveillance, inspection and periodic safety reviews.

4.2. Surveillance and Inspection

Many ageing issues can be picked up through the usual processes of continuous surveillance applied throughout the lifetime of all nuclear installations. These are: regular site inspections, incident reporting and other examinations pinpointed on concerns raised thereby.

One example of an I&C ageing problem which was identified is that of the generic problem concerning the embrittlement of elastomer anti-shock mountings on I&C cabinets. These have needed to be replaced throughout in order to maintain the equipment seismic qualification. An example of monitoring is the yearly reporting to the Safety Authority on the digital hardware, which reports analyze faults and reliability rates and should enable to show up any generic (end of life) trends. Safety Authority inspections at NPP sites, operator design offices and principle I&C systems suppliers premises, also address aspects of maintenance and management of modification for I&C systems.

Elsewhere, the operator has informed the Safety Authority of its specific life duration programmes for I&C (detailed in later paragraphs).

4.3. Ten-year Safety Review

A periodic safety review is required every 10 years by the French Authority. It is on this occasion, which is associated with a major plant outage for maintenance, that each NPP must demonstrate its aptitude for safe future operation over the next 10-year period. Prior to the 10-year safety review, specific evaluation studies are completed for the NPP series and safety objectives and requirements may be changed (this is known as updating the safety referential). Compliance has to be demonstrated, inspection, tests and re-qualification may be required for some components. It is also a point when the programme of plant modifications is consolidated and the safety report is updated.

The 30-year safety review for the earliest of the CP series 900Mwe NPP is a particular milestone for the safety demonstration concerning ageing. In preparation for this, a specific examination was carried out by IRSN for the Safety Authority to evaluate the overall organization and methodology for manageing ageing issues and plant life together with the strategies and programme of actions taken by the operator to assure safe future operating of

Standing Group at the end of 2003. The conclusions were that the operator's methodology and organization for overall ageing management are suitably adapted with respect to safety assessment objectives.

Some specific points for detailed clarification concerning the I&C ageing management have been asked for. This will be seen in the following paragraphs.

5. REVIEW OF FRENCH OPERATOR'S PLANT LIFE MANAGEMENT PROGRAMMES

5.1. Overall Approach and Organisation to Plant Life Management / Plant Life Extension

Since 1980 Electricity de France has been engaged in a number of projects and programmes for plant life management and plant life extension. In its overall approach, which covers all types of plant systems, structures, equipment and components, the operator describes the following roles and objectives:

- to structure input data – so as to be able to capitalize on all the data for ageing effects, to manage assets – by the development of methods for techno-economical optimization and also the renewal of the generating capacity, to analyze the external environment — looking at international or non nuclear industry experience and,
- to propose the life cycle management strategy.

These lead to a number of continuous actions, notably:

- updating existing maintenance programmes,
- development of methods for repair or replacement, and
- initiating new R&D work.

The operator does not have a unique and fixed organization specifically for ageing management. However, the processes of ageing management are addressed essentially by four organizational entities having specific and complementary functions as follows:

- normal maintenance — maintaining the reliability of I&C components by assuring appropriate repairing or replacement and thus performing a continuous renewal of the NPP equipment,
- exceptional maintenance — planning and anticipation of major repairs or replacements,
- ten-yearly outages / safety review — bringing the formal evidence that adequate management of ageing is achieved over a ten-year period,
- life duration programme — coordinating and maintaining for the future the right level of management of ageing covering the points mentioned in the paragraph "overall approach" and others.

Elsewhere in the organization, plant operating procedures could be modified to reduce solicitation of equipment and human resources need to foresee sufficient levels of adequately trained staff for the future.

5.2. Preparation for the 10-year Safety Reviews

In the initial generic studies that were carried out in 1987 the I&C was defined as one of the "sensitive" components for the life duration of a NPP. The NPP I&C was categorized into the following types:

- instrumentation and actuators,
- cabling,
- relays,
- «discrete» controllers,
- analogue electronic «integrated» systems,
- digital electronic «integrated» systems,

The studies concluded that the last 2 categories were the most problematic and initial assessments concluded on difficulties in maintaining original systems longer than 25 years because of obsolescence. The operator took the option to aim to keep the I&C equipment operational for a period of 20 to 25 years after the start of the industrial service of the plants. In order to achieve this, a policy and a programme of actions referred to as "life duration" process was put into place by the operator and systematic studies were started in preparation for the 10-year safety reviews.

In preparation for the 2nd 10-year safety review for the CP and the P4 series NPP, the operator started projects to re-evaluate the "life duration" of the I&C and to propose strategies for maintenance or renovation.

Between 1993-1995 the operator carried out a study of the CP 900MWe NPP series I&C, with the objective to assure operability of the I&C over the period corresponding to the 2nd (and up until the 3rd) 10-year safety review, i.e. for the earliest plant, 1998-2008.

Another study was carried out between 1996-1997 to assess the P4 1300MWe NPP series I&C with the similar objectives (operability between 2005-2015 for the earliest NPP of this series).

Both of these studies considered the following:

- ageing effects,
- obsolescence,
- stressors (operating conditions),
- operating experience,
- state of equipment and components (visual inspections and destructive analyses),
- replacement strategies,
- maintenance procedures,
- spare parts inventory,

- commercial availability of electronic components,
- supplier support contracts.

These results of operating feedback analysis and expertise of the condition of the I&C equipment enable the operator to envisage maintenance of the majority of the existing I&C at least until the 30 year NPP safety review. These conclusions, however, depend on implementing a procedure for I&C life-cycle with guaranteed support from the suppliers.

Given that the functional needs are stabilized, preventive maintenance is optimized and that problems of obsolescence are anticipated by component stocks, the need for I&C renovation remains limited. The needed renovations target essentially the replacement of equipment adversely affected by thermal ageing or the optimization of the treatment of obsolescence. A number of actions concerning partial modernization and specific maintenance actions were taken as a result. These include:

- the partial modernization of the CP series reactor protection I&C (neutron flux measurement),
- the remaking of some analogue cards for the CP I&C,
- modifications to improve environment (ventilation) P4 process control digital cabinets to increase operating lifetime,
- parts stocking to counteract obsolescence,
- improvements to routine maintenance (analysis of operating experience highlighted the areas where better training and procedures could minimize inadvertent damage fragile components during intervention),
- establishing supplier support contracts and protocols for the future.

5.3. Formal Safety Demonstration for the 30-year Safety Review — Ageing Analysis Files and Aptitude to Pursue Operation Dossiers

For the 3rd 10-year safety review of the CP series (i.e. 2008 for the earliest NPP), the operator will make a formal demonstration concerning ageing management to the Safety Authority. An "Aptitude to Pursue Operation Dossier" will be established for the structures, systems, equipment and components of the NPP that are deemed to be "ageing sensitive" for the following 10 year operation period.

The method for identifying the 'ageing sensitive' items is based on a systematic analysis considering the different ageing mechanisms affecting all components installed in the various locations of the NPP taking account of their safety importance. This information is classed and maintained up to date in the form of individual "Ageing Analysis Files" for selected components which have already shown to be effected by or may potentially be subject to an ageing mechanism (i.e. a couplet ageing mechanism(s) + material, equipment type, implantation zone affected). In June 2003, 446 ageing analysis files had been produced for the CP 900Mwe type NPP of which 43 are relative to the electrical and I&C.

The analysis identifies which equipment types are susceptible to ageing and considers such points as the safety importance (using safety class and probabilistic safety analysis), evidence from operating experience, provisions in the design, whether the maintenance is or can be suitably adapted, the possibilities for repair and replacement, and obsolescence risks. From this, the decision to produce a special “Aptitude to Pursue Operation Dossier” for the safety demonstration is made.

The control systems, some cabling in hot spot environments and the electrical cable junctions to the containment have been identified as requiring an Aptitude to Pursue Operation Dossier. The Ageing Analysis Files for the instrumentation conclude that the maintenance is in general adapted, although the final analysis for some instrument transmitters is pending.

IRSN have made several recommendations to improve the detail and the traceability of the ageing analysis files. The operator is currently updating and completing the analyses.

5.4. 30-year Safety Review of the CP 900MWe Reactor Series I&C

The I&C studies (2003–2004) currently underway concern the life cycle for I&C during the 30 to 40 year period of operation of the CP series (i.e. 2008 – 2018 for the earliest NPP). These consist, on the one hand, of reinitiating studies along the same lines as those for the 20-year review as described in the above paragraphs.

On the other hand, another study is considering the feasibility of implementing any future foreseeable functional modifications needs which may arise in the 30–40-year plant lifecycle or beyond (e.g. due to plant design life extension, changes in grid demand or operating modes, etc.). The implementation of possible application modifications foreseen during future utilization of the plant may pose some difficulties for the existing I&C even if it has been demonstrated to be capable of operating satisfactorily in its existing state. The existing equipment may be already fully utilized (saturated), it may be technically under-specified with respect to future application requirements, or else, because of obsolescence, there may no longer exist the technical support or parts availability.

6. TREATMENT OF RECENT DESIGNS

6.1. Newest Plant — N4

The N4 reactor may be the newest but its digital I&C started becoming out of date even before the official industrial service authorizations! The long term lifecycle strategy for N4 I&C has meant establishing close liaisons between the operator and the system builder and manufacturer for support of “discontinued products” and client specific software. To counteract obsolescence, the operator must organize a comprehensive replacement parts inventory (e.g. the RUPI integrated circuits used in the process control PLCs are now out of production).

The Safety Authority has effectively monitored this obsolescence within the context of the modification management. As an example the latest N4 version updates programmed for installation in 2006/7 include some evolutions to cover obsolescence of certain peripherals for the computerized control room. Also certain evolutions of N4 digital I&C systems are necessary for long term support and maintenance. For example, adopting de-facto industry technology and protocol solutions enables compatibility with more commonplace replacement components (enabling for example the use of PCs for operator consoles and maintenance terminals).

6.2. Future I&C — EPR

The next generation reactor EPR will be implemented using the state of the art I&C solution available and is intended to have an even longer operational lifetime (60 years). It is thus very important to consider, at the initial design stage, the I&C lifecycle and the replacement strategies for the future.

Some orientations for future reactor series or on renovated installations can be taken from the experience of maintaining the current systems:

- the operator preferred strategy for developing I&C systems is to make maximum use of commercial products and avoid all modifications which are susceptible to transform them into custom client products that may be difficult to maintain in the long term,
- long term maintenance must be taken into account at the system design stage and should be a part of requirements documents for the call to tender,
- the modularity of the I&C architecture should facilitate progressive renovation,
- the design should consider the portability of software solutions to new hardware platforms.

7. REFERENCE

[1] French safety authority review “Contrôle” n° 129 June 1999

ANNEX C.2.

COUNTRY REPORT ON I&C AGEING MANAGEMENT IN THE PAKS NPP, HUNGARY

J. Eiler
Paks Nuclear Power Plant Ltd, Hungary

1. ABSTRACT

The four units of the Paks NPP have been in commercial operation for an average of 17 years. The original design lifetime is 30 years. Lifetime extension is an important part of the Paks NPP's strategy. The actual task is to evaluate the technical, economic, operational and legal conditions of lifetime extension, considering also the deregulated electricity market. The plant's objective is to provide firm bases for lifetime extension by lifetime oriented operation, maintenance and ageing management. In this country report, the different aspects of I&C ageing management in the Paks NPP are outlined.

2. REGULATORY APPROACH

The safety aspects of the ageing phenomenon and ageing management are well defined in the Hungarian Nuclear Safety Regulations, issued in 1997. One of the objectives of the Periodic Safety Review prescribed in the regulation is to assess the stage of plant ageing and to demonstrate the adequacy of plant activities in ageing management. Four very detailed Regulatory Guidelines are now available on the subject topic, covering the following areas:

- RG 1.26 - Requirements of authority inspection of ageing management
- RG 2.15 - Quality assurance of ageing management in the NPP
- RG 3.13 - Assessment of the ageing phenomena in the design phase
- RG 4.12 - Requirements for ageing management during operation

3. AGEING MANAGEMENT OF I&C COMPONENTS

It is generally thought that the overwhelming majority of the I&C equipment is replaceable. (It would, however, cause significant difficulties to change certain parts, i.e. the full extent of I&C cabling, in reality.) Taking into account the possibility of changing the equipment in certain periods, it is kept mainly a reconstruction and maintenance task to provide and preserve the required functionality of the I&C systems and components, for virtually any extension of the plant lifetime. The I&C ageing management strategy is adjusted to this basic approach.

Initiated by the formerly mentioned regulatory approach, systematic activities started in 1997. In the identification of critical I&C parts for ageing management, the following components were classified as critical: control rod drives, containment penetrations, and instrumentation cables and connectors. Today it is obvious that the list is significantly longer and additional items are taken under surveillance. Examples of these additional components are: different types of sensors and transmitters, junction boxes, pneumatic valve controller devices, certain types of instrumentation valves, indicators, hand switches, etc.

Under the umbrella of the I&C ageing management project, the following main categories of ongoing activities need to be mentioned:

- Ambient condition monitoring for critical I&C equipment
- Equipment qualification for the real environmental conditions
- Artificial ageing (at a moderate and expedited speed) and subsequent testing of selected components to validate the residual lifetime
- Equipment and system reconstruction to cope with ageing, obsolescence and technical inadequacy

For the purpose of this report, selected examples will be described in each category.

3.1. Identification of Relevant Environmental Conditions Inside Containment

In the Paks NPP, it was suspected that actual temperature and radiation parameters in the containment, at the location of specific I&C components, were higher than it was set up in the design bases. To provide valid input for ageing management, it was decided to monitor actual conditions in designated areas.

A comprehensive monitoring of temperature and gamma dose was started in 1997, in one of the Paks units. 40 temperature sensors were installed in critical cabling locations and other I&C installation areas in the containment. Battery powered data loggers collected temperature information for one year during normal operation. In addition to temperature monitoring, 33 gamma dose capsules were placed in critical locations for subsequent evaluation.

In the next refueling outage, the dose monitoring capsules and the temperature loggers were read out and data were evaluated. The entire monitoring process was then repeated in the remaining three units.

The main conclusions were as follows: Temperature distribution inside containment was highly inhomogeneous. The average temperature at different I&C installation locations ranged between 56 0C and 95 0C. Thermal load on the cables was significantly higher than originally estimated. It is a widely accepted experience that a 10 ^{0}C decrease in ambient temperature may slow down the ageing effect to half of the original speed. Therefore, several mechanical and civil measures were taken in Paks to provide a lower environmental temperature in the most critical areas. The gamma dose was close to that in the design bases. It meant that its effect on ageing was in the range that was previously calculated.

3.2. Equipment Qualification

Equipment qualification has been considered a major task to assess residual lifetime of selected I&C components. It has been performed for different types of pressure transmitters, cable junction boxes and pneumatic valve controllers, to date. One of the main reasons for choosing physical qualification in place of pure calculations was the unavailability of original equipment qualification data from the supplier. In the process, real environmental data input came from the monitoring project described in the previous section. For the first run, a 15-year equivalent life period was selected for artificial ageing, and a LOCA testing was also conducted at the end of the simulated lifetime.

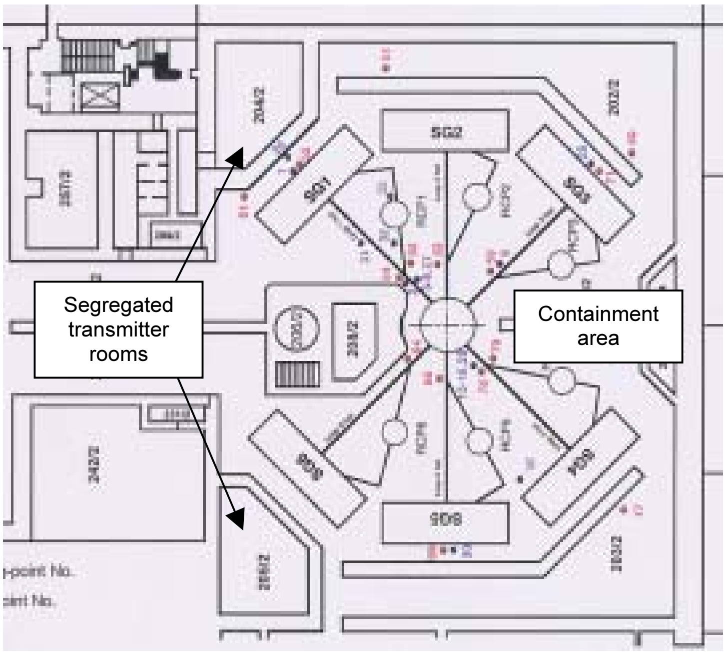

Figure 1. Segregated transmitter rooms in a WWER 440 unit.

It needs to be noted that in a WWER-440 type NPP the pressure transmitters are not installed in the containment. There are segregated transmitter rooms for each safety train and instrumentation tubing is run from the containment to these rooms through hermetic penetrations (see Fig. 1.). As a result, for the I&C equipment installed in the mentioned rooms, not a LOCA is the most severe situation. A rupture of a pressure sensing line would aggregate harshest circumstances, but it would still be much milder than a LOCA in the containment. Consequently, at the qualification of these devices, these milder environmental conditions were taken into account. (see Fig, 2.)

Figure 2. Environmental qualification of pressure transmitters.

All of the equipment tested so far has successfully passed the qualification process for 15 years. It is now planned that a broader range of critical components be taken under the same qualification, and, on the other hand, equivalent time used in the qualification be altered from 15 years to an extended lifetime.

3.3. Validating the Maximum Expected Service Lifetime

For an example of the subject activities, cable ageing and testing will be outlined in this section.

In the 1997 and 1998 refueling outages, a systematic visual inspection of the in-containment cables was conducted. During these walk-downs, cable samples of the most commonly used three types of I&C cables were collected. A rigorous test programme, described later in this section, was then conducted on representative samples. Other, identical specimens were deposited in a cable depot for expedited ageing and subsequent testing.

The depot was installed in Unit 2 in 1997, on one of the reactor coolant loops (see Figure 3.). Initially, there were 28 cable and connector samples deposited. These specimens had been in service for 15 years under in-containment conditions before placing them in the depot. In each subsequent annual refueling outage, partial samples were removed from the depot for testing, while new samples were deposited. Based on the temperature and dose monitoring conducted in the depot it became known that the acceleration rate of ageing was significantly higher than it was planned originally. Therefore, it was decided to remove the existing depot in 2001, and a new one was installed in Unit 1 in 2002, at a longer distance from the reactor vessel.

Figure 3. The cable depot on a reactor coolant loop.

The thorough test programme that was conducted on the original samples and also on the subsequently removed specimens from the depot every year, went through the following sequence:

1. Determination of isolation resistance
2. Determination of elongation at rupture of the wire insulation and the cable outer jacket
3. Accident range irradiation
4. Determination of isolation resistance after irradiation
5. Determination of elongation at rupture after irradiation

6. Forced ageing under accidental circumstances (90 ^{o}C and 135 ^{o}C, saturated steam, overpressure) for the time period a LOCA, while monitoring the isolation resistance
7. Subsequent ageing at 60 ^{o}C for 135 hours (equivalent to the post-LOCA conditions), while monitoring the isolation resistance
8. In the last phase of the above step, a total submerge under water while monitoring the isolation resistance
9. Final determination of elongation at rupture

Figure 4. The LOCA testing vessel.

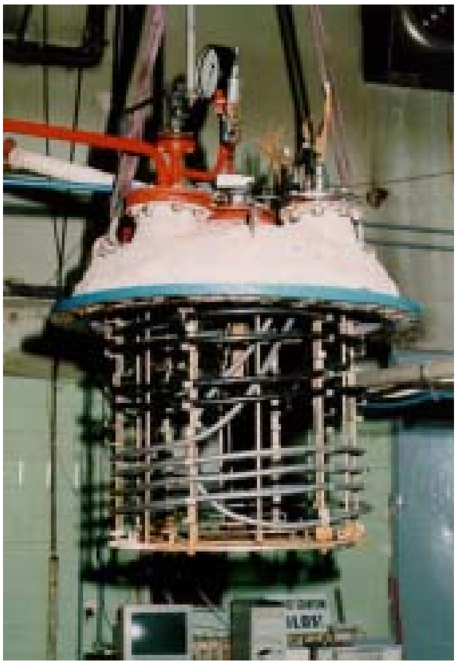

Figure 5. Cable samples prepared for testing.

Applying the above depicted, annually conducted testing, it was possible to assess cable suitability for LOCA conditions (with the expectation that the LOCA occurs at the very end of the service period) for a series of longer and longer lifetime values. In the overwhelming majority of test parameters, a well-detectable deterioration was found. The annually repeated tests, however, did not always show an unambiguous tendency in the long run. In some cases some examined parameters did not show deterioration from one year to the other. It may have come from the fact that too few test series have been conducted yet, and statistical fluctuation may exceed the real deviations.

It was confirmed that monitoring the isolation resistance of the cable provides no direct results with regard to the ageing condition of the cable. Testing the elongation at rupture gives a much more realistic basis for this estimation.

Inside containment, several hundreds of relatively short (3 to 10 m) interconnection cables are used between local junction boxes and the connecting end-devices (sensors, motor-operated valves, etc) Based on the test results and the calculated ageing conditions, it was decided to replace all of the mentioned cables. This change (600 cables, to date) always came together with the replacement of the local junction box, too.

3.4. I&C System and Component Replacement to Cope with Ageing

The majority of the Paks I&C equipment was designed in the 60s and early 70s. The Russian instrumentation has been in operation for 20 years now, which led to a complete obsolescence in several cases. To cope with this and with ageing problems, a systematic and very comprehensive replacement of I&C systems and components has been launched and mostly conducted. Below, some examples of this activity can be found:

3.4.1. Safety I&C system (RPS) refurbishment

The considerations for the necessity of the Reactor Protection System Refurbishment were complex. Aged and obsolete equipment and the shortage of spare parts supply could have caused great problems. The volume of maintenance work required for ensuring the needed reliability reached a rather high level. A significant volume of preventive maintenance was required for the electromechanical limit switches and certain relay circuits.

After a long-lasting preparatory work, a contract was signed with Siemens in 1996 to replace the old safety I&C system with a state-of-the-art, digital solution, integrating the following, formerly individually realized functions:

- Reactor Shutdown System
- Ex-core Neutron Monitoring System
- Emergency Core Cooling System
- Emergency Diesel Generator Start-up and Load Sequencer
- Reactor Power Limitation System
- Steam Generator Protection System
- Loss of Plant External Power Supply Automation

All the hardware (TELEPERM XS) and software design was conducted by Siemens for the first three units, while Hungarian software was developed for Unit 4. The project concluded in the last unit in 2002.

During the definition of the functionality of the new RPS, the national and international operational experiences and the results of WWER unit studies were also considered and resulted in major functional modifications.

During the design phase, a 3-level functional specification was used:

- Natural language description
- Synoptic functional diagrams and database
- Detailed functional specification using the SPACE system for Teleperm XS from Siemens

A representative configuration of the new safety I&C system was installed in the full-scope training simulator (see Figure 6.). Validation of the new safety I&C system in realistic operational situations was greatly facilitated using the full-scope simulator, and the majority of specification and design errors was revealed this way, before the real plant installation took place.

Figure 6. The representative configuration of the Teleperm XS safety I&C system

Major experiences with the new system showed two spurious EP-1 operations during the commissioning of Unit 1, due to improper adjustment of overlapping algorithms in the Neutron Flux monitoring system. A failure and minor quality problems occurred with one of the components in the neutron flux measurement part, as well as in specific power supply modules. Except for the mentioned problems, approximately 10 unit-years of smooth and undisturbed operation proves the suitability of the system in the past 4 years.

3.4.2. Plant computer reconstruction

At the start-up of the Paks units, CM2 type Russian computers were installed. The old machines were in operation for nearly 20 years. They became entirely aged and obsolete in their hardware, software and functional features.

After the conclusion of a successful pilot project, the NPP decided to conduct a replacement with a distributed SCADA system, based on state-of-the-art hardware and software solutions. About 10 000 input points per nuclear unit are processed, displayed and archived in the new system (see Figure 7.).

The reconstruction project was closely connected to the safety I&C system refurbishment, as the new process computer provides the secondary man-machine interface for the safety system, too.

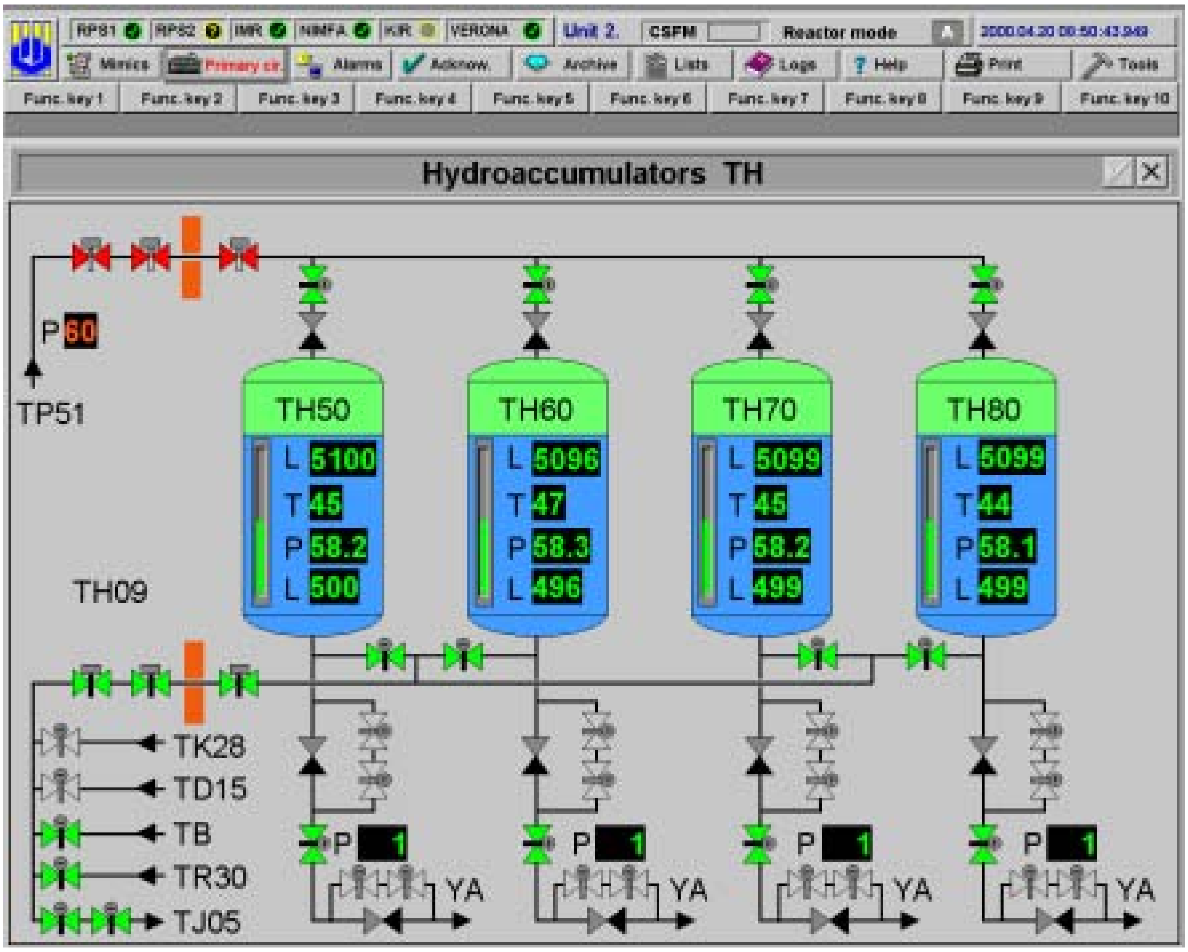

Figure 7. Typical mimic in the new process computer system.

A built-in WEB server provides information to remote workstations, which are installed out of the process computer network, on the plant Intranet. These are, for example, engineering workstations and ordinary office PCs at different departments of the NPP.

After the TMI accident the US NRC has initiated the introduction of Safety Parameter Display Systems in the US NPPs (NUREG-0696). At this same time, the Emergency Operating Procedures (EOP) have been rewritten as symptom-oriented procedures. At the Paks NPP, the preparation of the new EOPs was finished (with Westinghouse's assistance) in 1999, and a computerized Plant Safety Monitoring and Assessment System (PLASMA) was also developed to support the execution of the new EOPs. This was the most significant functional extension in the new process computers.

3.4.3. Turbine controller modernization

The goal of this project was to establish capabilities of participating in the countrywide primary frequency control, which, in turn made it possible for Hungary to join the European supply system. Under the scope of this project all four units were equipped with state of the art, digital turbine governors in the former years.

The DIGIREC 920 equipment was supplied by CEGELEC, France and the design change was supported by Hungarian design organizations. Hungarian firms carried out the system installation, too. The operational experience gathered so far is very favourable.

3.4.4. In-core monitoring system reconstruction

This activity resulted in an entire replacement of the original Russian HINDUKUS systems. The new monitoring equipment was supplied by Hungarian vendors. It consists of five data acquisition cabinets for field signals. This part of the system is based on VME Bus controllers, collecting core neutron flux, core temperature and other conventional process parameters.

The data acquisition equipment is connected to two central computers, which are redundant pairs of each other. These computers run very complex core calculations and present the calculated information on operator workstations installed in the main control rooms. This reconstruction provided for substantially more precise calculation results, allowing a significant increase in output power without any relevant modification to the plant process equipment.

After the installation of the new safety I&C system, several input signals to the in-core monitoring system were eliminated and the corresponding information is now taken from the Siemens TELEPERM cabinets.

3.4.5. Automatic fire detection and extinguishing system modernization

The original fire detection and extinguisher system was installed at the beginning of the 1980s and its capacity has become fully exploited. The level of automation was low and the system was highly maintenance demanding. In order to increase reliability and operability, to comply with expanding demands and to avoid spurious alarms due to failures, a total system replacement was launched in 1997. The selected new system came from CERBERUS (Switzerland). It comprises more than 1000 input sensors, and about 80 alarm annunciation devices in each unit. Physical installation started in 1998 and has been carried out in all four units to date.

3.4.6. Pressure and differential pressure transmitter replacement

A systematic dP transmitter replacement was initiated more than 10 years ago and continued in the past years, too. At present there are about 1080 new transmitters installed in the units (see Figure 8.). There are four types of Rosemount transmitters in use:

- 1151: Standard type
- 1151-T: Standard type with nuclear cleaning
- 1451: Special design for WWERs.
- 1151-S: Smart transmitters

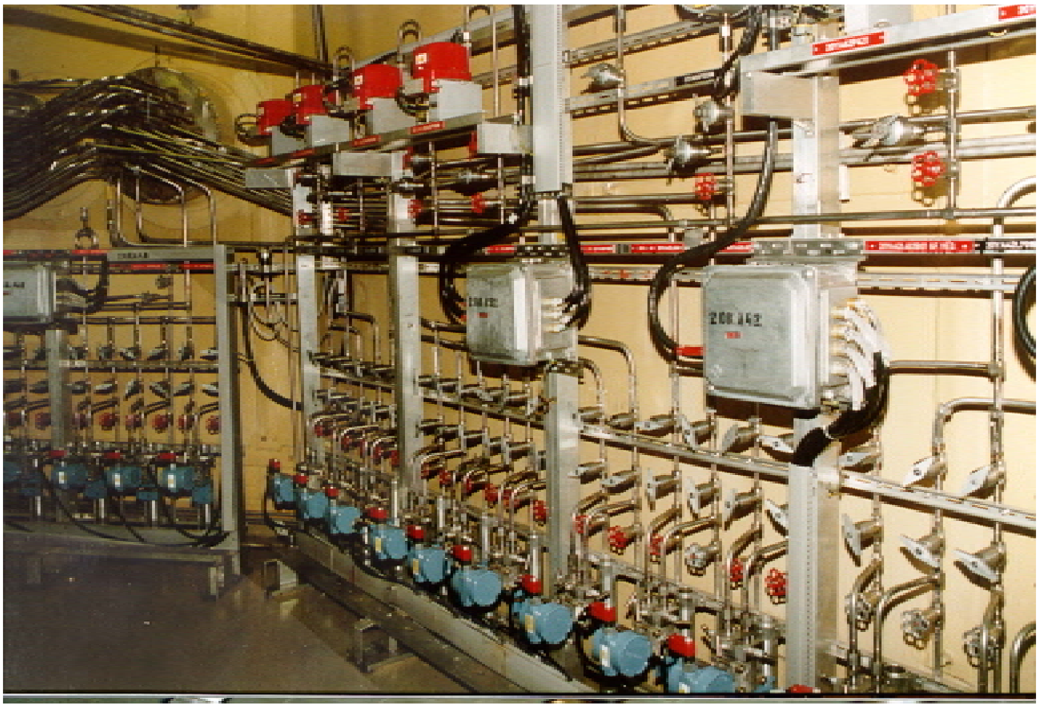

Figure 8. Rosemount transmitters in the reactor building.

The subject activity was extended with the change of pressure transmitters starting in 1996. About 600 instrument loops were equipped with Hartmann & Braun made AMD-200 type pressure transmitters. The project is going to be carried on in the upcoming years.

3.4.7. Replacement of electromechanical indicators with limit switches

The comprehensive replacement of the originally implemented electromechanical limit value switches (the Russian KPU's) began in the NPP in 1992 and concluded in 1998. At present nearly 1000 new, fully electronic limit value monitors (Hartmann & Braun INDICOMP) are in service. The replacement has been finished in the ECCS logic rooms involving 850 devices in the four units. The remaining 150 indicators were installed in control rooms.

3.4.8. Recorders

A systematic replacement of the obsolete Russian made recorders started at the power plant. Altogether in the four units, 74 recorders have been replaced with HONEYWELL made instrumentation. The new devices provide some practical services, like event controlled recording. The project has been suspended, as new technologies have become available in the meantime. It is now under consideration to phase out the possible maximum number of conventional, paper-type recorders and reconnect their input signals to the new plant computer for archive.

3.4.9. Containment wall penetration changes

A gradual deterioration in insulation resistance has occurred in the original Russian hermetic penetrations feeding the reactor control rod drives, due to moisture and humidity. Therefore, a systematic replacement of these devices has been launched. 88 penetrations out of about 100 have been changed until now, and more devices will be replaced in the upcoming years. Simultaneously, new penetrations were installed serving the needs of the new reactor protection system. The amount in this latter case was 40 altogether. The Hungarian VISOLA

Ltd supplied the new penetrations, while the internal glass and wire elements were manufactured by SCHOTT in Germany.

3.4.10. ECCS tank level instrumentation modernization

At the initiation of this activity, there were miscellaneous arrangements and logic designs used in the measurement loops in question. After an evaluation of the emerged problems, a complete replacement of the existing equipment was decided. The new, unified instrumentation consists of PHOENIX made, floating type level meters. The installation started in 1997 and finished in 2000. The number of new devices is 36 in each unit, respectively.

3.4.11. Control unit replacement of pneumatically operated valves

The original supplier, HERION ceased manufacturing the types of control units used earlier in the Paks NPP. Therefore, spare parts supply has disappeared. Due to this reason, a systematic replacement of the pneumatically operated valve control units has been launched. To date, approximately 250 out of the 720 extremely expensive assemblies have been changed in the four reactor units. This project will last for several additional years, with an average number of 50 to 90 device changes in each year.

4. SUMMARY

As it is seen today, there are good chances for a significant lifetime extension in the Paks NPP for keeping the company as a competitive alternative, the dominant factor in the domestic electricity market. Within the framework of this task, ageing management is a key issue. Based on authority regulation requirements, as well as on the long term experience of plant operation and maintenance, the NPP launched a systematic ageing management programme. It has its subtasks in the I&C field, too. Cable ageing is considered as the most significant I&C ageing issue in this plant. Several tests and qualification activities have been carried out to identify and validate the residual lifetime of critical I&C components. A very comprehensive system and equipment replacement project have concluded to cope with, among others, ageing and to keep this middle-aged plant in a good shape for a long term.

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ANNEX C.3.

CURRENT STATUS OF CABLE AGEING MANAGEMENT AND RESEARCH IN JAPAN

T. Yamamoto
Japan Power Engineering and Inspection Corporation (JAPEIC), Japan

1. ABSTRACT

Various research and development activities are taking place in different Japanese institutions on monitoring and evaluation of the cable ageing effect in nuclear power plants. This paper gives a summary of the above-mentioned activities, focusing on cable condition monitoring and the evaluation of ageing cables.

2. CABLE CONDITION MONITORING

2.1. Non-destructive Diagnosis Method for the Ageing Cables

It is necessary to develop the non-destructive diagnosis method in order to carry out cable condition monitoring. So, in Japan, the development of a non-destructive diagnosis method for the ageing cables was begun several years ago [1]. In the development of the method, the following matters were executed.

1. Evaluation of ageing indicator
2. Evaluation of the applicability of basic techniques (See Table 1)
3. Acquisition of non-destructive diagnosis data
4. Evaluation of the correlation between ageing indicators and non-destructive diagnosis data
5. Applicability study of non-destructive diagnosis for ageing cables

a. Electrical techniques	b. Chemical techniques	c. Physico-chemical techniques	d. Physical techniques
• Dielectric loss tangent • Potential damping • Residual voltage • Time domain reflectometry	• Elemental analysis • Gas detection • Hydrogen halide gas generated • Carbonyl group generated • Oxygen consumed and gas generated • Molecular weight	• Spectrochemical analysis • Chemi-luminecent analysis • Thermo-gravimetric analysis • Oxidation induction time	• Twist torque • Surface hardness (Rebound hardness) • Surface hardness (Indentation depth) • Changes of thickness • Bending stress • Stress-Distortion response • Propagation velocity of ultrasonic waves

Table 1. Basic evaluation techniques

As a result, the elongation at break was appropriate to the ageing indicator. And the non-destructive diagnosis methods using the propagation velocity of ultrasonic waves and the surface hardness were applicable to the cables used at nuclear power plants.

2.2. Example of a Non-destructive Diagnosis Method for a Cable

The principle of the non-destructive diagnosis method using propagation velocity of ultrasonic wave is shown in Figure 1[1]. As shown in Figure 1, two probes are used to transmit and receive ultrasonic waves, which have been injected in the direction of the cable axis. And first of all, the propagation time T1 of ultrasonic wave at the distance L1 between the probes is measured. Next, one probe is moved and the propagation time T2 at the distance L2 is measured. The propagation velocity of ultrasonic wave is calculated from the distance difference and the propagation time difference.

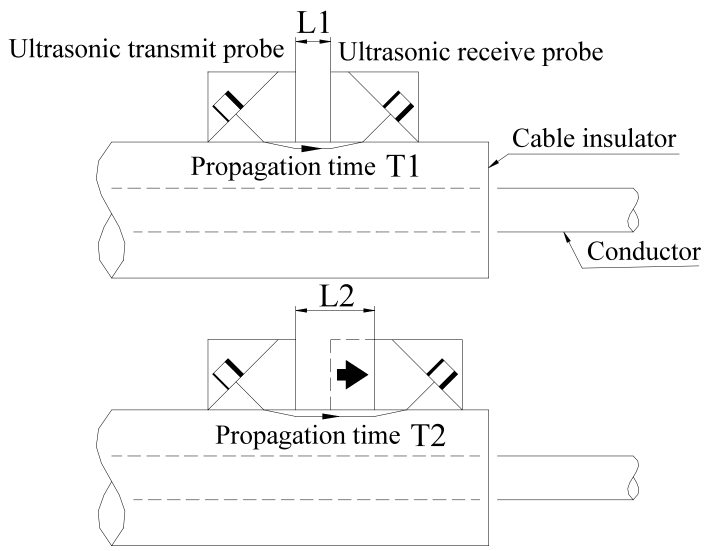

Figure 1. Principle of Ultrasonic Wave Propagation Velocity Measurement.

2.3. Application of Cable Condition Monitoring in Nuclear Power Plants

In Japan, cable condition monitoring has been applied in some PWR plants beginning in 2000 [2][3]. In PWR plants, two methods are used for the cable condition monitoring. One is the method of using propagation velocity of ultrasonic wave; this method is applied to the cables insulated with EP rubber and PVC. Another one is the method of measuring surface hardness; this method is applied to the cables insulated with silicone rubber.

The diagnosis devices using propagation velocity of ultrasonic wave and surface hardness are shown in Figures 2 and 3. And the situations of using a diagnosis device in a nuclear power plant are shown in Figure 4. Here, this diagnosis device uses ultrasonic waves.

Figure 2. The diagnosis devices using propagation velocity of ultrasonic wave [2][3].

Figure 3. The diagnosis devices measuring surface hardness [3].

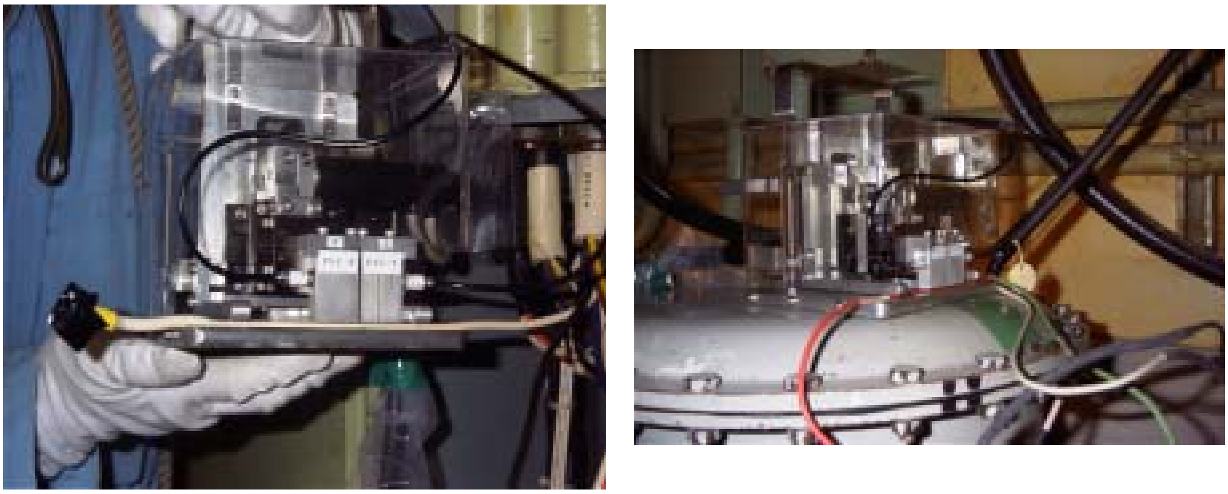

Figure 4. The situations of using the diagnosis device in a nuclear power plant [2][3].

2.4. A New Technique for Cable Condition Monitoring

A new technique with the application of optical diagnosis for detecting cable degradation is researched [4]. In this technique, light sources of two wavelengths are used and the change in reflective absorbance between the two wavelengths is measured. And, difference of this reflection absorbance is used to predict the lifetime of the insulation. When the insulation darkens as a result of degradation, the reflective absorbance increases, that is indicating an increase in cross-linking density due to degradation.

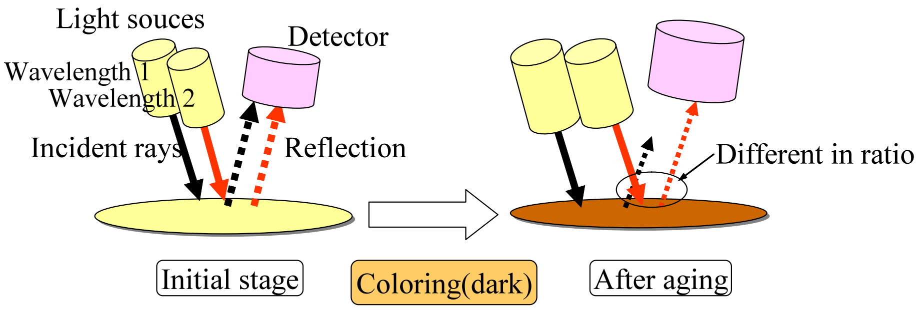

Figure 5. Outline of diagnostic principle [4].

3. EVALUATION OF AGEING CABLES

The chief content of this chapter was presented at the International Conference on Wire System Ageing [5]. In here, the evaluation of ageing cables is equated to the evaluation of whether the cable has an appropriate environmental qualification.

3.1. Current Evaluation of Ageing Cables

In Japan, the technical assessments to various equipment including cables are regularly executed in nuclear power plants that became old. In the current evaluation for the technical assessments of the ageing cables used in a nuclear power plant, we were executing a classification of the cables, a selection of the representative cable by cable and insulator type, and an evaluation of the representative cable in accordance with IEEE Std. 323 and 383 [6]. The findings derived from these evaluations are that most of the cables maintain the electric function capabilities under the assumption of 60 years operation.

An accelerated ageing method is used to evaluate the ageing cables. The topics for current accelerated ageing methods are as follows:

1. The conditions for accelerated thermal ageing are estimated by extrapolating the activation energy, which is evaluated by the Arrhenius plot obtained in a relatively high temperature range.
2. The irradiation at high dose rate (<10kGy/h) is permitted.
3. The irradiation is carried out sequentially after the thermal ageing.

However, in the above-mentioned accelerated ageing method, there are uncertainties to simulate the actual cable ageing more precisely, according to recent findings. So, we summarized these uncertain issues related to the evaluation of ageing cables.

3.2. Issues in Evaluation of Ageing Cables

The issues that we consider as important for the evaluation of ageing cables with an environmental qualification test are as follows:

1. Accelerated thermal ageing condition (How to estimate the activation energy).
2. Dose rate for radiation exposure.
3. Sequence of thermal ageing and radiation exposure.
4. Judging method of cable integrity.

3.3. Plan for an Assessment of Cable Ageing

JAPEIC started the project, "Assessment of Cable Ageing for Nuclear Power Plants" in the 2002 fiscal year to establish a highly reliable evaluation method for cable ageing, under the auspices of the Ministry of Economy, Trade and Industry (METI).

We have made a plan to execute a thermal ageing test for evaluation of activation energy and a simultaneous ageing test for establishment of a new evaluation method by using the cables of 14 types that include 6 types of insulation materials. A thermal ageing test will be conducted at 3 conditions in total within the temperature range in which uniform degradation occurs inside the insulator. The maximum duration of the thermal ageing test at the lowest temperature is planned to be 4 years.

We have made a plan to conduct a simultaneous ageing test in which various dose rates and temperatures are combined, so as to establish a new evaluation method using a master curve that might be able to be used as an estimation model of the ageing cable. A simultaneous ageing test will be conducted at 9 conditions that combine 3 dose rates in about 3-100 Gy/h and 3 temperatures. And, we planned to obtain continuous degradation data for a maximum of 4 years.

We planned to carry out the DBE exposure test including radiation exposure for cables used in a reactor containment vessel after the simultaneous ageing test. In the DBE exposure test, a steam exposure test is performed after DBE irradiation. And the integrity of ageing cables will be judged after the DBE exposure test.

We will publish this result at the end of the 2008 fiscal year.

3.4. Information on Environmental Qualification of Cables

Research on low accelerated ageing of the cables has been executed [7][8] before the research of the JAPEIC. Figures 6 and 7 are announced in report at ICONE11 in 2003 [8]. Figure 6 shows an example of the master curve for EP rubber that superposes the various simultaneous ageing data.

Figure 7 shows an example of the master curve for silicone rubber. The superposing technique used here was based on the technique proposed in IEC 1244-2. In this report the tendency of the deterioration of the cable in various environments can be predicted by using this master curve. Moreover, the cable maintenance programme using the master curve and the cable CM is described in this report. Please refer to the report for details of the cable maintenance programme.

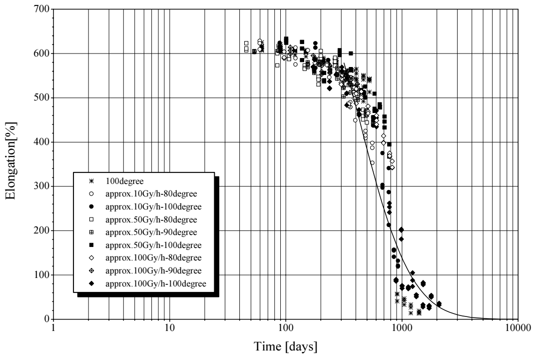

Figure 6. Example of master curve for EP rubber [8].

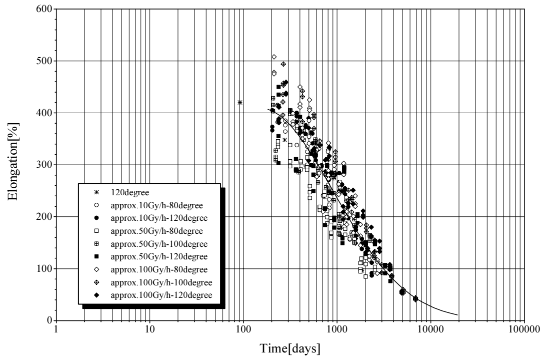

Figure 7. Example of master curve for silicone rubber [8].

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ANNEX C.4.

COUNTRY REPORT ON PLANT LIFE CYCLE AND AGEING MANAGEMENT IN THE REPUBLIC OF KOREA

Kook Hun Kim
KNICS R&D Center, Republic of Korea

1. ABSTRACT

In the Republic of Korea, 18 NPPs have been commercially operating since the first operation of Kori Unit 1 in 1978. Yonggwang Units 5 & 6 have just started commercial operation, while the process protection system, the process control system and the monitoring system of Kori Unit 1 were replaced with semi-digital systems in 1998.

As one of the most dynamic countries in the fields of new NPP construction as well as the replacement of old I&C systems, Republic of Korea's status and direction for the life extension and I&C ageing management policy may impact the world market and technology.

In this report the experiences and technologies on I&C components' ageing management and upgrade of I&C subsystems are summarized. This report starts with general information on the Republic of Korea NPPs in Section 2. Then the maintenance and ageing management of component level are described in Section 3. The upgrade of I&C subsystems of Kori Unit 1 is summarized in Section 4.

2. GENERAL INFORMATION ON KOREAN NPPS

Since the first commercial operation of Kori Unit 1 in 1978, the number of Korean NPPs increased quickly and the total generation capacity of NPP is the 6th in the world. Including Yonggwang Units 5 & 6, which started commercial operation in 2002, the number of commercial NPPs in the Republic of Korea becomes 18 and the capacity is 15,718 MW at the end of 2002.

This means that the share of NPPs is 29.2% of the country's generation facilities. Actually the nuclear power generation of 2002 reached about 119 billion kilowatt-hours which is about 38.9% of the country's total electricity generation of the year.

In addition, four units of Korean Standard Nuclear Power Plant (KSNP; PWR, 1,000MWe) including the KEDO LWR project are under construction and eight new constructions of NPPs are scheduled.

Table 1 on the next page shows the status of NPPs in operation and new construction plan in the Republic of Korea.

CATEGORY	UNIT		OUTPUT (MWe)	TYPE OF REACTOR	STARTING DATE OF COMMERCIAL OPERATION
IN OPERATION	KORI	#1	587	PWR	1978. 4.29
		#2	650	PWR	1983. 7.25
		#3	950	PWR	1985. 9.30
		#4	950	PWR	1986. 4.29
	WOLSONG	#1	679	PHWR	1983. 4.22
		#2	700	PHWR	1997. 7. 1
		#3	700	PHWR	1998. 7. 1
		#4	700	PHWR	1999.10. 1
	ULCHIN	#1	950	PWR	1988. 9.10
		#2	950	PWR	1989. 9.30
		#3	1000	PWR	1998. 8.11
		#4	1000	PWR	1999.12.31
	YONG-GWANG	#1	950	PWR	1986. 8.25
		#2	950	PWR	1987. 6.10
		#3	1,000	PWR	1995. 3.31
		#4	1,000	PWR	1996. 1. 1
		#5	1,000	PWR	2002. 5
		#6	1,000	PWR	2002.12
SUBTOTAL		**18**	**15,716**		
UNDER CONSTRUC-TION	ULCHIN	#5	1,000	PWR	2005. 6
		#6	1,000	PWR	2005. 6
IN PREP. FOR CONSTRUC-TION	SHINKORI	#1	1,000	PWR	2011. 9
		#2	1,000	PWR	2011. 9
		#3	1,400	PWR	2011. 9
		#4	1,400	PWR	2011. 9
	SHINWOL-SONG	#1	1,000	PWR	2010. 9
		#2	1,000	PWR	2010. 9
IN PLANNING	-	#3	1,400	PWR	-
		#4	1,400	PWR	-
SUBTOTAL		**10**	**11,600**		
TOTAL		**28**	**27,316**		

Table 1. Status of NPPs in the Republic of Korea

3. AGEING MANAGEMENT OF I&C COMPONENTS

It is known that the operating condition of plants is more sensitive to I&C system and components than other hardware components in NPPs, as well as in thermal power plants. Especially, as I&C is directly related to the normal operation and protection of NPPs, ageing of a component can stop the plant operation and/or lead to a severe malfunction. Another severe problem in nuclear I&C is obsolescence. It comes from the fact that nuclear I&C uses proven technologies and devices, which means that even in the newly designed and produced I&C systems relatively old-fashioned components are used. Therefore, in most cases, after 15–20 years of operation obsolescence becomes a common problem.

The ageing degradation of I&C components affects the safe, reliable operation of NPPs and increases the unplanned shutdown rate, which affects the availability and safety of NPPs. Therefore, it is very important to adequately manage the ageing degradation of I&C components for lifetime extension as well as safe and economical operation of NPPs. This management should assure the designated safety function of the plant systems and maintain the ageing degradation of them below the acceptable limit.

I&C component degradation occurs as a result of long term operation and exposure of material to harsh environment, such as radiation, temperature, humidity, pressure, and dust inside the containment and mild environment inside cabinets. This component degradation is expressed in the form of corrosion, fatigue, cracking and reductions in fracture toughness due to neutron irradiation and thermal embrittlement.

3.1. Korea's Regulatory Approach in Electrical and I&C Equipment

In the Republic of Korea, the regulatory guideline concerned with the ageing of the electrical and I&C equipment is fundamentally defined in the third Clause of Article 42 of Enforcement Decree of the Atomic Energy Act related to the Periodic Safety Review of NPPs. And the second Clause of Article 19 of Enforcement Regulation of the Atomic Energy Act includes the following related details:

- Classification and selection of structures, systems and components (SSCs) for Periodic Safety Review
- Ageing analysis of SSCs for Periodic Safety Review
- Function and safety margin of SSCs according to ageing
- Prediction of performance degradation time and future condition of SSCs
- Measures and management plan of reduction of ageing degradation of SSCs

The third Clause of Article 19 of Enforcement Regulation of the Atomic Energy Act, prescribing the basis of Periodic Safety Review, defines the guidelines ordering the designated safety function of the plant systems should be maintained against the time-dependent ageing-related degradation. Also the safety functions should be guaranteed and margin of SSCs should be acquired by planning, and through following of the ageing management programme. The ageing evaluation of I&C components has been carried out according to the ageing management programme based on the above regulations.

3.2. Activities of Ageing Management

The ageing management of I&C components has been systematically and consistently performed to keep the components in good condition since the first commercial operation in the Republic of Korea.

Under the control of the nuclear utility called Korea Hydro & Nuclear Power (KHNP), a designated company for I&C system maintenance, Samchang Enterprise, is continually monitoring and checking the status of I&C systems, as well as periodic detailed inspection during the scheduled plant outage. In this section, the ageing management method of printed circuit boards (PCBs), relays, thyristors/diodes, air operated valves (AOVs), cables, and so forth, is explained.

3.2.1. PCBs

PCBs, being composed of many electronic chips, electric-electronic devices and complex-thin patterns for control signals and power, are very sensitive to an electric shock/environment and can cause an unexpected, abrupt failure of normal operation. Another point is that, since PCBs are inserted to a rack through a socket, which can be a weak point to mechanical vibrations, the electrical and electronic connector pins could be easily contaminated or electrically damaged. This makes the needs for careful inspection and ageing management of PCBs be one of the most important ageing management processes.

The first stage of inspection is checking materials susceptible to ageing. The main ageing concern of PCBs is cracking by radiation embrittlement. Secondly, ageing of chips and devices are checked by visual inspection. Finally, electronic characteristics are evaluated using commercial test tools. The checking process of PCBs and the related test equipment are shown in Figure 1 and Figure 2, respectively. Through the inspection and ageing management procedure the integrity of single components in the PCBs, as well as normal operation of PCBs can be checked.

About 4,000 PCBs have been tested and evaluated every year by the procedure since 1993. In fact, 38 unexpected shutdowns occurred before adopting the process (from 1978 to 1992) because of PCB problems. Possibly, some of the unexpected shutdowns could be the results of infant mortality phase faults and/or operation/maintenance mistakes. No shutdown caused by PCB faults has occurred for 10 years since the introduction of the process, which shows the effectiveness of Korea's PCB maintenance procedure. This procedure may be one of the key contribution for KHNP to keep the world top class availability of NPPs. KHNP and Samchang Enterprise are proud of this process.

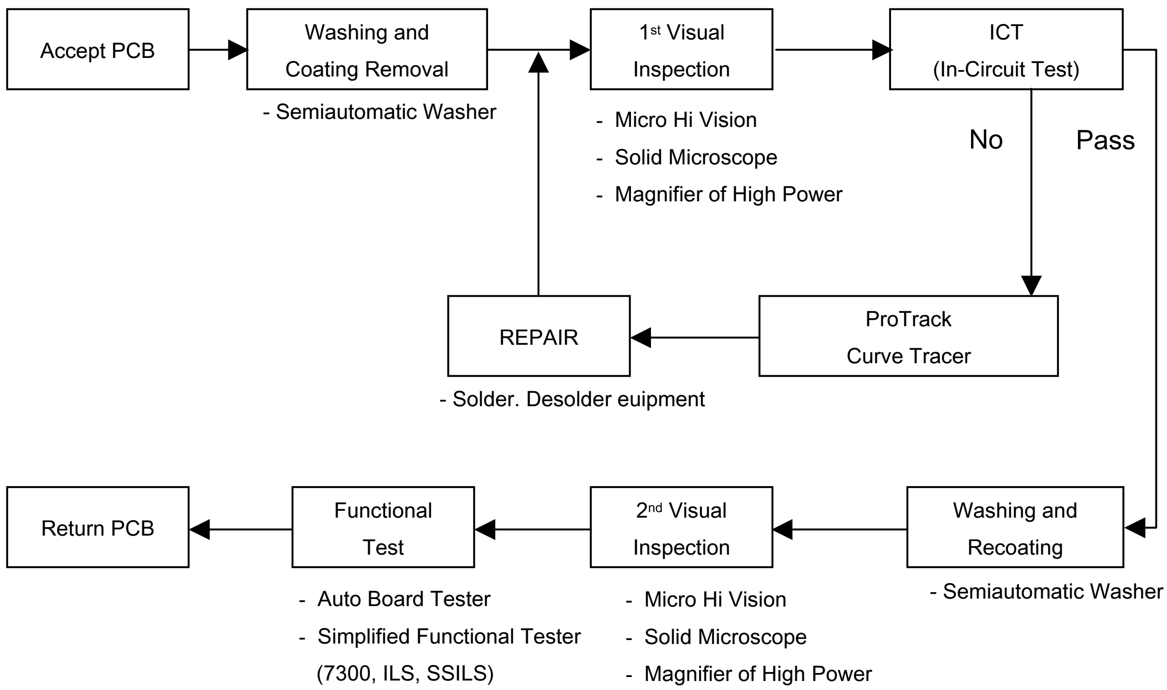

Figure 1. Checking process of PCBs.

Figure 2. Test equipment for PCB check.

3.2.2. Relays

Relays are electro-mechanical or solid-state devices and used in protective and control applications in NPPs. There are various kinds of relays such as protective, auxiliary, control, time delay or timing, and electronic ones. As relays are usually located in relatively mild environments, such as the inside of a cabinet, they are likely to be affected by the condition of mechanical, electrical, thermal, and environmental stressors. These conditions may affect the operability of moving parts, heat dissipation, contact corrosion and insulation integrity. The symptoms of such ageing degradation include changes in response time, coil characteristics, contact characteristics, and so forth. Ageing concerns are mainly coil failure, contact failure, binding/mis-operation, setpoint drift, dielectric breakdown, and shorts by various ageing mechanisms.

The various types of relays are periodically checked and tested for the management of the above ageing degradation. For this ageing management, a specially developed tester is used. The relay characteristic tester automatically measures contact resistance, coil resistance, operating voltage, close voltage, operating time, and close time by test signal injection and measurement.

Figure 3. Relay test tool.

3.2.3. Thyristors and diodes

Thyristors and diodes are mainly used in the regulators for conversion of AC power to regulated DC power, such as battery chargers, control systems and driving of CRDM. In order to function correctly, it is very important to manage ageing degradation of thyristors and diodes. The ageing concerns of thyristors and diodes are short or open failure. Such ageing degradation occurs by ageing mechanisms such as thermal ageing, thermal stress, fatigue and fouling or by abnormal electric shocks and over voltage and/or current.

For the management of ageing degradation, as well as other kinds of failures, a thyristor/diode testing equipment was developed and used to check the condition of ageing process, which is different from the PCB checking procedure. This process can estimate the status of the devices and contribute to the enhancement of the system reliability and availability. About 1100 thyristors/diodes were checked for three years from 1999 to 2001.

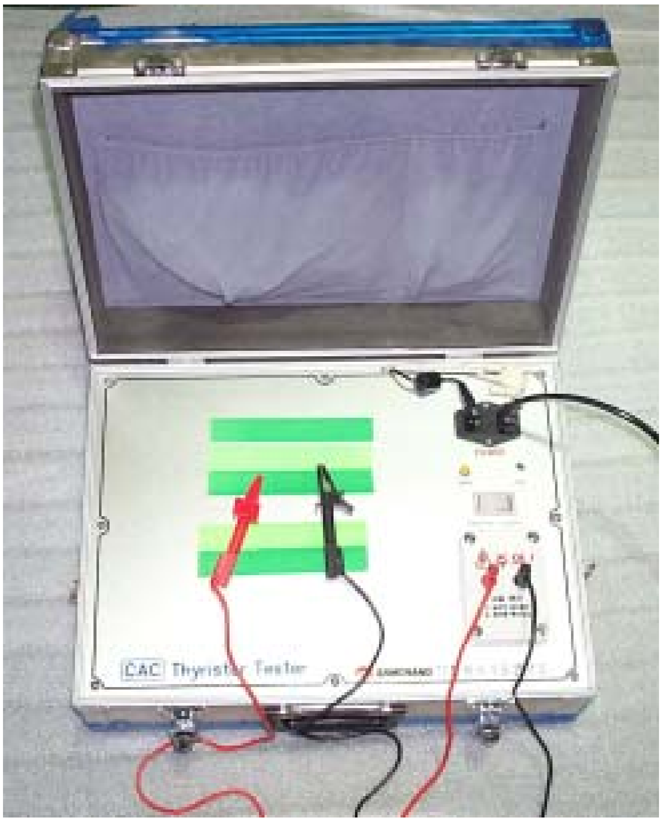

Figure 4. Thyristor tester.

3.2.4. AOVs

An AOV is usually used for process control systems in NPPs. The response characteristics of an AOV are important to manage the ageing degradation. In order to measure the response characteristics, an AOV calibrator was developed in 1997 and has been used to test the integrity of main valves since 2001. Since the history of response characteristics of AOVs is stored as a database by this equipment, the ageing degradation may be efficiently managed.

Figure 5. AOV calibrator.

3.2.5. Cables

Cables are important equipment to transmit electrical power and various signals in NPPs. Cables in NPPs should be identified to ensure that it is possible to correctly perform their function after occurring DBA as well as during normal operation of the NPP. Thus, life evaluation and lifetime management of cables are closely connected with lifetime extension of NPPs.

Because the lifetime of cables used in NPPs is about 40 years, which is almost the same as that of NPPs, ageing of cables had not been a matter of concern in the Republic of Korea. However, the lifetime extension of NPPs has become a hot issue and in some cases cable's lifetime is not guaranteed in the harsh environment. Therefore, the necessity of cable ageing management has become a major concern related to life extension.

The ageing of a cable is dependent on various factors, such as the material of cable, environmental conditions, temperature and radiation, which depend on the function and location of cables, such as control, AC power, DC power, signal and communication. The ageing degradation of a cable is usually found from the change of mechanical characteristics rather than electrical. The main ageing concerns are leakage currents and cracking by radiation ageing and embrittlement.

The best way to evaluate cable ageing is to take out the installed cable from the NPP and inspect it carefully. However, it needs almost the same hard work as the replacement of equipment and cable. Thus, it is actually impossible. An effective method is ageing simulation. Accelerated ageing simulation serves useful results within a reasonable time. This method performs accelerated ageing for cables and equipment in a short period and simulates the ageing process and condition of equipment occurring during the operation of an NPP for several decades. Since the first commercial operation of an NPP in The Republic of Korea was started in 1978 at Kori Unit 1, the ageing management of cables has not been an essential process so far. However, KHNP has got to the concern about the ageing problem of cables in NPPs since the first NPP in The Republic of Korea is now 25 years old, so ageing management for cables becomes essential for the lifetime extension of the NPP. As an effort, the ageing management technology of cables has been studied as a research project in The Republic of Korea, which is carried out by a research team of Korea Electric Power Research Institute. The result of the research project will be applied to NPPs sooner or later. Below is a summary of the current ageing management methods that will be applied to the installed cables.

The accelerated ageing method is based on the Arrhenius equation that assumes that the rate of the thermal ageing mechanism decreases with the inverse of the temperature. The related constants of the equation are measured by test facilities, and used to simulate and evaluate the mechanical ageing degradation of a cable that is aged in isothermal and intermittent heating conditions. However, this method includes several uncertainties, such as accelerated ageing by high temperature and radiation, incorrect activation energy, test procedure, test error and test samples. Therefore, it is desirable to perform this method after monitoring the temperature and radiation in the NPP at least for 2 years.

Although this method has a lot of advantages, the most substantial method of lifetime evaluation may be the periodic inspection of the test samples that are installed on-site from the initial operation of NPPs.

Lifetime management of cables needs condition monitoring. Monitored items are electrical, mechanical, chemical characteristics of cable materials and the function of the cable. To monitor the above physical values, various types of condition monitoring equipment have been developed in The Republic of Korea. The developed equipment for monitoring of cables are a portable cable intender for measurement of the hardness of cable jackets, and a cable elongation multi-tester for measurement of elongation rates of cable. Also, a temperature and radiation recorder for monitoring environmental temperature and radiation, and an electric furnace for activation energy generation are in progress of development.

These activities are expected to be helpful for increasing availability as well as extending the lifetime of NPPs.

Figure 6. Portable cable indenter.

4. UPGRADE OF THE I&C SUBSYSTEM IN KORI UNIT 1

Kori Unit 1, the first NPP in The Republic of Korea, has been commercially operating since 1978.

The original designated lifetime of the unit was 30 years. However, thorough evaluation of the main equipment tells us that the plant life cycle could be extended up to 40 years. Consequently, the ageing management and upgrade of I&C systems has become a hot issue. Especially, the upgrade is necessary because of obsolescence problem.

4.1. General Introduction to Kori Unit 1

The information of Kori Unit 1 is shown in Table 2 and Table 3.

Output (MWe)		587
Type of Reactor		PWR
Containment	Material	Steel
	Inside Diameter (m)	32
	Pressure (psig)	43
	Volume (m³)	41,000
Reactor Coolant System	Number of Loops	2
	Number of Fuel Assemblies	121
	Inside Diameter of Reactor (m)	3.35
	Coolant Temperature (ºC) (Cold/Hot)	282.6 / 320.2

Table 2. Plant generals

System	Before Upgrade	After Upgrade in 1998
Reactor Trip System	Relay Logic (WH)	Relay Logic (WH)
ESFAS System	Relay Logic (WH)	Relay Logic (WH)
Protection Process System	Foxboro H-Line	Spec200/Spec200 Micro (Foxboro)
NSSS Control System	Foxboro H-Line	Spec200/Spec200 Micro (Foxboro)
BOP Process Control System	Foxboro H-Line	Spec200/Spec200 Micro (Foxboro)
Turbine/Generator Control System	Relay (GE)	Relay (GE)
Plant Computer System	W-2500 (WH)	XM-7000 (Woori Tech. Inc.)

Table 3. I&C Specification

4.2. Replacement of I&C Subsystems

Most of the I&C systems in Kori Unit 1 were designed in the 1970s. As operated for about 20 years, they have become aged and obsolete, and their ageing degradation has affected the safety and reliability of the plant. In addition, there have been significant advancements of

I&C technology over the past 20 years with improvement of digital 3C field: computer, communication and control.

Therefore, it has been required to be upgraded with new equipment based on state-of-the-art hardware and software to improve the safe and reliable performance of the plant.

For the I&C upgrade of Kori Unit 1, a preliminary technical review for improving the aged I&C subsystems was carried out from October 1996 to January 1997. As a result, the common problems were mainly as follows:

- Low reliability and availability due to ageing
- Difficulty of maintenance due to ageing
- Obsolescence of the same model

Taking account of the above, the systematic replacement of the I&C subsystems listed below has been carried out from July 1997 to December 1998:

- Process Protection System
- Process Control System
- Plant Monitoring System

4.2.1. Process protection and process control system

At the start-up of Kori Unit 1, the H-Line from the Foxboro Company was installed as the plant protection and plant control system. This equipment has been in operation for about 20 years since the first installation in 1977 and has become aged. However, as this model was obsolete in 1989 according to the technical transition from analog to digital I&C, obsolescence problem has urged to upgrade the aged analog I&C to a new one. In addition, its ageing was affecting the normal operation with bringing safety, reliability and availability of the plant down. Therefore, it was necessary for all the H-Line, from H-Line equipment to I/P converter, to be replaced by new ones.

H-Line was replaced with a new system, Spec 200/Spec 200 Micro of the Foxboro Company. The local transmitters, I/P converters, and the other instruments were also replaced with new ones satisfying the specification of the new system. The system, which is composed of 3 modules, performs the same function as the old one and provides the plant with more improved and reliable functions than the old one.

4.2.2. Plant monitoring system

The W-2500 of Westinghouse Electric Company designed in the 1970s, was installed in 1977. As the follow-up measures of the TMI accident, an Operator Aid Computer System (OACS) was installed in 1993 and received the signals of the Plant Monitoring System in parallel, which was interfaced with the application programme, such as the distribution of neutron flux, in-core neutron flux monitoring, primary and secondary performances. OACS was also exclusively receiving the monitoring signal except the application programme in charge of W-2500.

However, because of frequent incidents by the aged W-2500 and obsolescence of the same model, it was difficult for the plant to maintain the normal operation. As a result of the preliminary technical review, the following problems showed:

- Low reliability due to ageing
- Low memory capacity and CPU speed of the computing equipment dissatisfying the quick transfer of operation information
- Limited judgment of operating conditions due to the absence of the graphic and shift display of operation
- Possibility of an operator's mis-operation due to the insufficiency of the operation information and the analysis function

The new model, XM-7000 of Woori Technology Inc. improved the function of MMI and the access capability to the plant information. This system is divided into a Data Acquisition System (DAS) and a Computer System and provides various functions such as the plant data acquisition, the monitoring of operation variables, diary recording, alarm, and application programmes for operators. Since the computer server and network communication, which is a main part of DAS, had a redundant structure, its availability was raised to 99%.

5. SUMMARY

I&C components and systems are closely connected with the safe and reliable operation of NPPs. As they are likely to be affected by environmental factors such as temperature, radiation, humidity, and electromagnetic wave, the ageing problem has been a main concern since the start-up of a plant. In addition, the enhanced transition from analog to digital I&C has made the previous analog I&C be obsolete.

In The Republic of Korea, taking account of this concern and the domestic electricity market, where a nuclear energy is a critical source with a thermal energy, the ageing management of the existing I&C for NPPs has been systematically and consistently performed up to date. I&C components such as PCBs, relays, thyristors/diodes, AOVs and cables, and I&C subsystems of Kori Unit 1, such as the process protection and process control system and the plant monitoring system have been systematically managed and upgraded with new ones in order to cope with ageing and obsolescence, and to extend the plant life cycle based on the regulatory guidelines and the experiences of the long term operation of the NPP. As the number of aged NPPs gradually increases in The Republic of Korea, the methods and techniques for integrated ageing management including monitoring and evaluating ageing, and developing ageing management programmes will make consistent progress to fully satisfy the regulation for licensing renewal of the existing NPPs.

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ANNEX C.5.

EXPERIENCE IN MANAGEMENT OF EQUIPMENT SERVICE LIFE IN RUSSIAN NUCLEAR POWER PLANTS

G.V. Arkadov, N.I. Barinov, A.V. Beloglzov, O.V. Ovcharov, A.I. Kononenko,
E.A. Mokrov, V.I. Pavelko, A.N. Trophimov, A.I. Usanov, B.M. Chernov
FSUE Research Institute of Scientific Instruments, Russian Federation

1. ABSTRACT

The activities implemented on management of I&C lifecycle at the Russian nuclear power plants enable today a smooth way of taking the license for an extended maintenance term of power units, the design cycle life of which have expired. The activities are regulated by both rules and norms prepared by a supervising body, and guidance documents developed by the major firm "Kontsern Rosenergoatom". Alongside with the complete modernization of I&C systems, which requires significant financial expenses, the following tasks are performed at the power units: diagnostics of conditions and life cycle prediction of separate types of I&C components; development and introduction of new operative methods for control of safety-related systems; creation of original sensors, the verification and calibration of which are carried out directly during operation. This approach allows to support a required level of I&C safety and to plan terms of their replacement. Examples of the performance of tasks on maintaining I&C operational stability at nuclear power plants are presented in this report.

2. INTRODUCTION

The extension of service life of the Russian power units beyond the designed thirty-year operation became possible only due to experience in management of the equipment ageing in nuclear power plants. For the last five years, NPP designers, manufacturers of equipment, supervision bodies, organizations of technical support (institutes and private companies) and, certainly, Rosenergoatom through its departments, and nuclear power plants themselves have been involved in the activities. The knowledge of ageing mechanisms and operating experience have allowed at the shortest time to solve problems connected with the methodology for extension of service life of systems and components important to safety; to identify their technical condition and to predict the time of their removal from service.

The methodology for extension of service life is formalized in the federal rules and norms prepared by the supervision body (NP-017-2000 “Main requirements for prolongation of NPP unit operation” [1]), and in guidance documents of the Rosenergoatom concern (RD-EO-0281-01 “Statement on management of the useful life characteristics of NPP unit components” [2]). One of the requirements of NP-017-2000 is formulated as follows: “Management of reliability (service life) of equipment, buildings, constructions and building structures of an NPP unit should be provided; for this purpose a service life management programme for these units should be developed and executed”. In RD-EO-0281-01 the procedure for manageing the service life characteristics of NPP unit’s components is described. In addition to RD-EO-0281-01, technical support organizations by the order of the Rosenergoatom concern are developing guidance documents on manageing the ageing of specific systems and components. These documents include methods for condition assessment and prediction of residual service life, as well as guidelines on further maintenance of systems and components.

These documents are based on the data on ageing mechanisms obtained, including, from inspections of systems and components when extending a service life of the unit. To such documents it is possible to reference RD EO 0322-02 “Statement on estimation of a technical condition and on management of cable ageing in NPPs” [3] and RD EO 0321-02 “Methodical instructions for technical condition assessment and reassigning a service life of relay devices in NPPs” [4].

The methods for technical condition nondestructive monitoring of a number of NPP SSCs are the key elements of the ageing management programmes. They may be divided into methods that can be used during scheduled repairs (for example, cable condition monitoring), and methods for operating monitoring (for example, vibration-noise diagnostics), used under reactor operation at power. The methods for operating diagnostics utilize the readings of both ordinary sensors and additional sensors. One of the aspects of ageing management is the development and introduction of sensors, which are verified and calibrated immediately in operation.

3. CONDITION ASSESSMENT AND AGEING MANAGEMENT WITH POWER UNIT COMPONENTS

In compliance with the design, a main body of I&C has a specified life and should be replaced irrespective of their technical condition in the time stipulated in the design or according to normative documents. For example, during “deep” upgrading on 3 and 4 units of the Novovoronezh NPP, all ordinary I&C were replaced with new ones. At the same time the replacement of all cable routes and devices of relay protection and automation (DRPA) was provided in accordance with the actual technical condition. Condition monitoring, prediction of residual service life and development of the guidelines on further operation of these products were implemented by FSUE RISI. Later on, the acquired experience was spread to power units of the Kola NPP, Leningrad NPP, and Bilibino NPP during the execution of programmes for service life extension.

3.1. Condition Monitoring and Cable Ageing Management

For today, the methodology of cable ageing management for NPPs has been developed. It is founded on knowledge of ageing mechanisms of polymeric insulation materials. Ageing of insulation materials was studied by data of both cable accelerated tests and investigations of their natural ageing. Key elements of cable ageing management programmes on NPP power units, undoubtedly, are qualification tests of new cables, non-destructive diagnostics of cables under service and on-going qualification of cables, for which it is necessary to confirm residual service life in view of design accidents.

The active implementation phase of the programmes for cable ageing management is progressing on schedule and starts on power units before operations on prolongation of the units service life over 30 years. Thus the following tasks are solved during these operations:

- identification of cables by type, service conditions, and functions executed;
- compilation of a database on safety-related cables;
- identification of service "hot spots";
- data analysis on defects of operating cables and power cables under test;
- selection of representative cables for condition monitoring;

- assessment of integrity of cable lines;
- condition monitoring of cables;
- qualification of hermetic zone cables for the given residual service life in view of possible effects of design accidents;
- prediction of residual service life;
- development of recommendations for the further service of cable lines.

The procedure for execution of these tasks is described in RD EO 0322-02. Many of these procedures are identical to those represented in the technical document of IAEA [5]. The features of their implementation on the Russian power units are given below.

3.1.1. Selection of representative cables for monitoring and tests

Experience has shown that the essential ageing of cables is observed only in operation in “hot spots”, i.e. in places where the intensity of degradation factors exceeds the average under operation. For identification of “hot spots” the following actions are performed:

- the analysis of operation and design documentation to identify “hot spots”, types of cables, failures of cables in operation as well as a route of walk-down of cable lines;
- the walk-downs of cables and interviews of staff are carried out according to the specially developed requirements with the purpose of detecting places with apparent abnormal conditions of cables;
- monitoring of temperature: in this case, either a thermal visual equipment is applied, which is very effective for recording of temperature distribution along cable lines on the operating power unit (in the hermetic zone, the thermal visual equipment is used in 2–3 hours after shut-down of the unit, then the observable temperatures practically correspond to temperatures on the operating unit), or temperature detectors with built-in memory, which are installed in “hot spots” during plant life cycle;
- radiation monitoring: as usual, about 50–100 PST-type dosimeters based on alumosilicate glass are applied to assess radiation effect on cables in the hermetic zone (the temperature of data readout for this dosimeter is equal to 350^{o}C, a value of fading is well-known [6]);
- determination of design accident conditions.

After the analysis of the findings, the route for carrying out of non-destructive diagnostics is set and samples of cables to be removed are selected for running of on-going qualification.

3.1.2. Monitoring of cable line conditions in operation

Now the “weight” of works on cable ageing management falls on monitoring of their condition in service. In the future, this "weight" of works will be shifted to qualification tests of new cable types on the new units, where cables are more resistant to degradation effects, and with putting into action the qualification tests with a smaller degree of conservatism.

Before carrying out of cable condition monitoring on a part of selected representative cables, the check for integrity of cable lines is performed using:

- time-domain reflectometry for searching local defects, which resistance is < 1 kOhm, and for identifying locations of moistening of cable lines, including moistening of penetration;
- bridge methods for searching local defects which resistance may reach 10 MOhm.

The following methods find the most widest use to determine a degree of cable ageing:

- local mechanical indenting of polymeric cable jackets (indenter measurements);
- taking of insulation and cable jacket microsamples of a few mg for subsequent investigation of change in their composition and structure by the following physicochemical methods: differential scanning calorimetry, thermogravimetry, IR - Fourier analysis;
- elongation at break for samples of cables removed from service;
- return voltage for power cables with paper-oil insulation (a method of return voltage is perspective as well for ageing assessment of control cables with different types of insulation).

3.1.3. Main reasons of cable ageing by the results of condition monitoring

Ageing of cables was caused by simultaneous effects of several degradation factors in the cable line locations because of:

- poor-quality installation of cables resulting in violation of cable jacket and consequent insulation ageing under exposure to elevated temperature (over 40^{o}C), humidity, radiation (more than 1 kGy/year), and mechanical vibration (the presence of fire protection covering complicates this situation – it is more difficult to detect defects);
- local overheating in a route caused by operating equipment, neighboring pipelines, and in points of the power cable connection to equipment, etc.;
- steam leakages of the coolant in cables near to pipeline valves;
- existence of locations with an increased level of radiation and temperature, for example, in the steam generator room;
- presence of reactive substances, for example, ingress of oil;
- high humidity for cables installed in protective metal pipes;
- overfall of heights in route, vibration from operating equipment and elevated ambient temperature for power cables with paper-oil insulation;
- possible effects of a maximal design accident (it can cause failure of a pre-aged cable with PVC insulation by electrical parameters, thus the mechanical characteristics of insulation materials may not reach the limiting values).

3.1.4. Recommendations for the further service of cables

The analysis of outcomes of condition monitoring has allowed to make specific proposals on operation of cable lines of safety-related systems:

- monitoring of service conditions (temperature, radiation, humidity, etc.) in “hot spots”;

- actions for reduction of service “hot spots” (installation of additional cooling, installation or restoring of thermal protection against heat sources, correction of possible steam effect by control of hermetic sealing of junction boxes, etc.);
- periodic cable condition monitoring in “hot spots” (application of modern, non-destructive, highly sensitive methods of diagnostics);
- to limit application of cables with PVC insulation in old power units under possible maximal design accident event that means step-by-step withdrawal of such cables from operation in places with service temperature above 40°C and condition monitoring depending on ambient temperature with a periodicity indicated in Table 1.
-

Table 1. – Service life (in years) of PVC/PVC KWWG cables in unit 3 of WWER-440 of the Novovoronezh NPP before the next condition monitoring

Ambient temperature, (°C)	Cable location	
	In-Confinement	Out-Confinement
40	28,1	64,8
45	16,6	39,3
50	10,0	24,0
55	4,3	14,8
60	2,7	9,2

3.2. Service Life Management of Relay Protection Logics and Automatic Facilities

The most comprehensive inspection of relay protective and automatic facilities (RP&AF), the main components of which are electromagnetic relays, was conducted in units 3 and 4 of the Novovoronezh NPP and unit 1 of the Leningrad NPP during works on prolongation of service life of these power units. The ageing programme in power units, as a rule, includes RP&AF of safety-related systems. The design stipulates that the transition of RP&AF to the ultimate state in these systems does not lead to disastrous consequences. The RP&AF maintenance is based on their actual technical condition, which monitoring is possible during scheduled-preventive repairs. For RP&AF, the processes of simultaneous ageing and obsolescence are characteristic.

For RP&AF, the mean operating time between failures is a normalized index of reliability, the mean restoration time is a normalized index of repairability, and the mean useful life is a normalized index of durability.

The primary tasks, which are solved under the management of RP&AF service life, are as follows:

- classification by executable functions, type, and service conditions;
- visual survey;
- accelerated laboratory tests (such possibility is realized only when it is possible to remove samples from service);
- instrumental control;

- statistical processing of data on defects and failures of both relays and component parts;
- assessment of residual service life by estimated and experimental methods;
- recommendations to further service.

3.2.1. Condition monitoring of relay protective and automatic facilities in a power unit

At the first stage of work, the analyses of the following things are carried out:

- project documentation and specifications,
- documentations available from manufacturers of RP&AF and its component parts;
- service form and records developed in NPP;
- documentation for the engineering maintenance system;
- reporting documentation on inspections, trials and investigations of defects, failures and malfunctions in RP&AF operation.

These measures allow to conduct their classification according to executable functions and type and to estimate the quality of maintenance and repair beforehand.

At the second stage of work, the visual survey is carried out to detect signs of wear and ageing, excess of thermal and electrical loads, mechanical and corrosion damages, and also with the purpose of estimating quality of mounting and dismantling on replacements of the component parts. Special attention is given to the condition of contact relay units and other commutative units of RP&AF. Their transient resistances were measured to check if there were suspicions of oxidation of contacts. Proceeding from external signs of wear and ageing, recommendations are given to the staff concerning the replacement of some relays.

The visual survey allows to test the correspondence of actual component parts of RP&AF to the technical documentation. Under external examination of the relays and other components of RP&AF, the year of manufacturing of these products is necessarily established. The experience of RP&AF examination has shown that the previous replacements of products of the same type in old power units were not frequently documented. Therefore, a production date of the relay may be a unique source of information when estimating the residual life of RP&AF, operating in a standby mode, as the life is spent mainly when carrying out an engineered function.

Knowing the periodicity or actual dates of maintenance and control, and a year of the component service start, it became possible to assess a residual service life of RP&AF at 75 % of the setting life, as a minimum for all components.

The instrumental control is a final stage of operations in the power unit. The instrumental control is required for check of the correspondence of operation parameters such as voltages, currents and operation time to their specifications and also for determination of actual operation modes of the relays and RP&AF as a whole. For measurement of the above indicated parameters of the relays it is enough to have a digital oscillograph furnished with a notebook.

During the instrumental control, the actual levels of climatic, mechanical and radiation effects on RP&AF are determined as well. From the instrumental control, recommendations are given to replacements of those relays whose parameters have overstepped limits of permissible ones.

3.2.2. Laboratory tests and assessment of residual service life

With extending the service life of RP&AF in units 3 and 4 of the Novovoronezh NPP, an opportunity offered to conduct as a matter of fact on-going qualification of these devices, using for this purpose the similar relays that have served over all the campaign in the temporarily closed down NV NPP units 1 and 2. For testing, the most severe of permissible operational modes for the given type of a relay were selected. The results of these conservative trials have shown that the transient resistance of the contact is the most vulnerable parameter of the relays. Other parameters of the relay (time, current, the operation voltage) were within permissible limits along the whole testing. The results of change in a contact resistance of the relay under tests for the commutative wear resistance are given below in Figure 1.

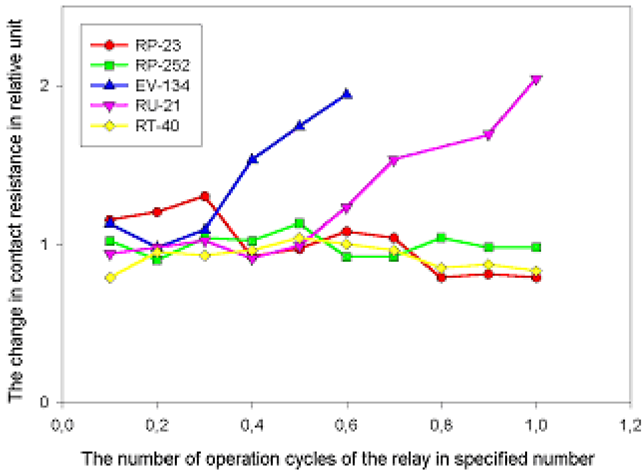

Figure 1. – Results of the relay tests for commutative wear resistance.

The statistical processing of data on defects and failures of the relays and other components of RP&AF obtained from the analysis of technical documentation and during the technical examination has allowed developing estimated - experimental methods for the evaluation of residual service life of electromagnetic relays and RP&AF as a whole from the results of their service. The most spread defects of relays are the breaking of clockwork drive of the time-delay relay and breakages or closure of relay coils. The lowest value of gamma-percent service life T0.95 = 34 years is obtained for EV–100 and 200 time-delay relays. For all remaining examined relays, T0,95 exceeds 50 years. This fact and also that the residual service life of the examined relays exceeds 75% of the target one have allowed to make a conclusion about the possibility to extend service life of the examined RP&AF from 9 to 15 years under condition of replacement of all EV–100 and 200 time-delay relays before the expiration of their gamma - percent service life.

3.2.3. Future possibilities and service conditions for electromagnetic relays

The safety maintenance under long term operation of RP&AF is grounded on the following statements:

- faultless maintenance;
- minimization of ageing and wearing effects;
- the technically proven replacement of critical components of RP&AF.

The first two positions are based on the maintenance and repair system and its scientific and technical support. The latter from the above-enumerated positions is actually defined by the common strategy of the branch on introduction of advanced designs of element base, including for RP&AF. At present, the works are being carried out on service life prolongation of RP&AF, which were designed and manufactured over three decades ago on the basis of an electromagnetic relay, obviously out-of-date from the point of view of technical advance.

For relays as well as for all products renewed after failure, a normalized reliability index is the failure rate γ or gamma-percent mean failure time $T\gamma$. According to the available information of the RAO ES, which combines the non-nuclear producers of electrical energy of the country, for 2002 a percent of false operations of relays was 0,5% for electromagnetic relays; 4,0% for electronic relays; 0,8% for microprocessor relays.

In terms of failure rate, the reliability of electromagnetic relays exceeds that of electronic ones and, at least, is on a par with that of microprocessor ones. In terms of additional index for products of a multiple cyclic operation, i.e. a minimum number of operations during $T\ \gamma$, the electromagnetic relays are at a disadvantage in relation to electronic and microprocessor ones. However, as the RP&AF inspection of emergency power supply systems and the own needs of units 3 and 4 of the NV NPP and unit 1 of the Leningrad NPP has shown, the number of relay operations for a 30-year service does not exceed 25 % of the prescribed figure.

Therefore, the replacement of electromagnetic relays with relays of a new generation, at least, does not improve the RP&AF reliability, and the introduction of new relays should be started in systems which do not concern those important to safety (for example, in systems of the main circuits).

4. DEVELOPMENT OF SENSORS WITH A POSSIBILITY OF IN-SERVICE VERIFICATION AND CALIBRATION

One of the major components of ageing management is the creation of equipment, in particular, sensors for NPP, which can provide calibration and verification without removing them from service. Thus, the process of calibration can be carried out automatically (self-calibration) or manually with the help of specially designed devices depending on the specific type of the sensor. New sensors of such type were created at FSUE Research Institute of Physical Measurements. Technical solutions, applied in instruments included in navigation systems and systems of artificial satellites orientation and space stations, where direct calibration and verification of instruments cannot be conducted, were used.

4.1. Sensors for the System of Industrial Anti-seismic Protection

For the system of industrial anti-seismic protection (SIAP) of the Balakovo NPP, a unit of seismic sensors BSD 1 have been designed which appearance is presented in Figure 4.1a, and for NPP "BUSHER", the similar unit SD 4 is being developed. The units of seismic sensors BSD 1 and SD 4 contain three orthogonally installed seismic receivers, which are static-dynamic accelerometers, and a processing circuit that implement the functions of weakening or amplification of accelerometer output signals, squaring, summing up, taking the square root, forming of standard output emergency discrete and analog signals.

A characteristic operational property of BSD 1 and SD 4 within SIAP is their "on duty" mode operation, i.e. they practically do not function prior to the occurrence of an earthquake or other seismic effects. In such operation mode the SIAP does not know whether the instrument is operable or not. Besides, as the units are measuring instruments, they should be calibrated periodically or verified for confirmation of their metrological characteristics. As a rule, the functional test of the sensors without their removal from objects of control is a rather complicated engineering task, anticipating the signal feed of the measured parameter at the input of the sensor, in this case, for example, a seismic effect with normalized parameters that is obviously unreal.

Figure 4.1a – Appearance of a transmitter BSD 1.

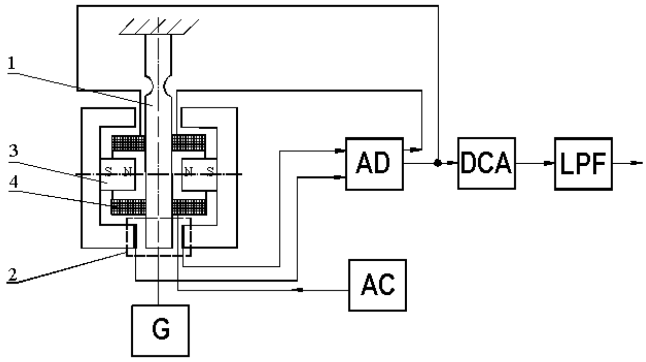

Figure 4.1b – The schematic of transmitter BSD 1 operation.

In the accelerometers used in BSD 1 and SD 4 for improvement of reliability and accuracy, and also for compensation of the influence of permanent gravitational acceleration, a scheme of equilibrium conversion was applied (Figure 4.1b). The sensing element of the accelerometer contains an elastic component (pendulum) 1, capacitive converter of movings 2 and magnetoelectric reversible transducer consisting of permanent magnet 3 and coil 4. The reversible transducer provides reproduction of a balancing force on the accelerometer element, recognizing acceleration (inertial mass). The electronic circuit of the accelerometer consists of a generator (G), amplifier - demodulator (AD), dc-amplifier (DCA), low-pass filter (LPF), and generator of automatic calibration (AG). Such a structure allows all measuring section to be verified and calibrated without the removal of the seismic sensor unit from the object of control and without disconnecting it from the SIAP. The given verification can be carried out both manually, for example, during incoming control, and automatically within the SIAP by its command. In sensors SD 4 a circuit of self-diagnostics has been inserted, in which the calibration is carried out periodically with the seismic sensors of unit SD 4 itself, without the request of the SIAP.

4.2. Sensor Monitoring System of Tension of Reinforcing Ropes

The protective ferro-concrete shields of reactors are in pre-stressed state that is provided with the tension of reinforcing ropes disposed inside the walls of the protective shield. As time goes on, the ropes are stretched and the tension is weakened. Control of a tension value of ropes is performed with the force sensors NV 005, which is a part of the system designed for the tension monitoring of reinforcing ropes. Figure 4.2a shows in-service installation of a sensor. The sensing components NV 005 are under measurement condition all the time, thus experiencing great loads (up to 1200 Ton) at ambient temperatures of - 45°C to 65°C. For these reasons, the deviations of the output signal may arise in the sensor. For 15 years they can reach a value of 2÷3%.

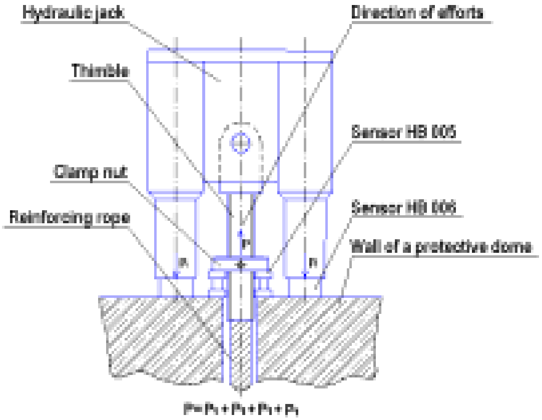

Figure 4.2a – Placement of the force sensor NV005 on the dome of the Balakovo NPP's reactor.

Figure 4.2b – Scheme of in-service calibration of the sensor NV005.

The sensors are located on the dome of the protective shield of the reactor at a height of about 50 m, their weight is 120 kg and to dismount them for calibration under metrological centre conditions, it is required to remove loads from reinforcing ropes at a considerable labor input. For the verification of the sensors without their dismounting the original technique using specially designed reference sensors NV 006 has been developed. The reference sensors are installed under four supports of a hydraulic jack (see Figure 4.2b), which, stretching a rope, weakens force affecting the sensor NV 005. The value of weakening measured by the sensor NV 005 will be equal to the sum of efforts applied to the sensors NV 006. Thus, the sensor NV 005 is calibrated in service without its dismounting. In this case the use of the NV 006 reference sensors does not require special metrological equipment, such as a hydraulic jack applied in order to provide tension of the reinforcing ropes.

4.3. Differential Pressure Transmitter for the System of Accident Localization

For the system of localization of emergency processes, the differential pressure transmitter DMV 001 has been designed. It is shown in Figure 4.3a. The sensor serves for measuring a rate of drop in pressure in pipelines of circuits I and II of WWER-type reactors. On the one hand, the differentiator performs its functions only under emergency conditions when the pressure within it is falling owing to rupture of the pipeline; on the other hand, the coolant pressure in the pipeline permanently effects on a sensing element of the differentiator (pressure differentiator Bm 212). The schematic diagram of DMV 001 is shown in Figure 4.3b.

For diagnostics of the differentiator, a special device – a calibrator – has been designed, which generates an electrical signal appropriate to a signal, coming to the input of an electric circuit of the differentiator from the sensing component (pressure transmitter Bm 212) with a particular rate of drop in pressure. When connecting the calibrator to a special diagnostic input of DMV 001, there is a signal at the output of the latter, which corresponds to the rate of fall in pressure specified by the calibrator. The value of the signal defines the service capability of the electric circuit of DMV 001. The service capability of the transmitter Bm 212 and its correspondence to metrological requirements is determined by a value of static pressure measured by it in the pipeline, which at the moment of the normal operating mode is known with an adequate accuracy.

Figure 4.3a – External appearance of the transmitter DMV 001.

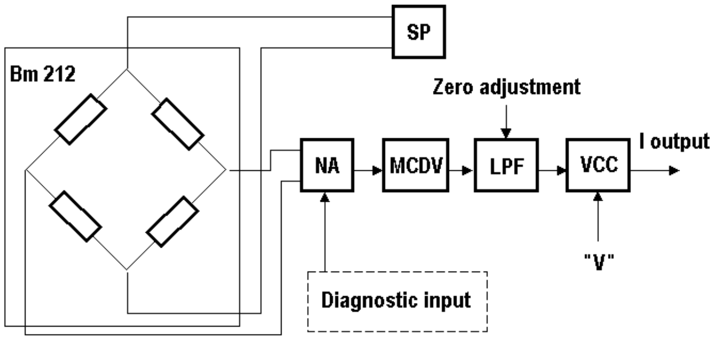

Figure 4.3b – Schematic diagram of DMV 001: Bm 212 - pressure unit, SP - stabilizer of power supply, NA - normalizing amplifier, MCDV – measuring circuit of drop in voltage, LPF – low pass filter, VCC – voltage - current converter.

It should be noted that DMV 001 uses a manual mode of calibration only because a variant of “the built-in calibrator" will require a large increase in the volume of the differentiator and its price.

The approaches to the design of the transmitters at issue are applicable also to other kinds of sensors and equipment related to instrumentation in an NPP. The sensors and instruments constructed on such principles allow to extend the service life of equipment, to improve operation reliability of different systems of NPPs and, finally, to improve NPP safety as a whole.

5. DEVELOPMENT AND INTRODUCTION OF NEW METHODS FOR OPERATIVE DIAGNOSTICS

One of the primary problems that are solved during upgrading of monitoring and management systems is the introduction of new systems of operative diagnostics (SOD) for a reactor installation and equipment, which fulfill functions missing in design systems. The main purpose of SOD is the detection of off-design effects on equipment and its off-design state at an early stage of their occurrence.

The systems of operative diagnostics allow reducing the degree of equipment damage, to lower probability of initial emergency events and as a result to improve the NPP safety. Besides, the SOD-based control allows to evaluate and forecast the real operational life of equipment so that by the beginning of the next audit to know “weak” spots of equipment, first of all, subject to repair or replacement, i.e. to conduct scheduled-preventive maintenance according to real technical condition and not just on due dates. In this sense, the systems of operative diagnostics are the information support of the periodic control systems.

The developer of the SOD for WWER in the Russian Federation is ZAO “DIAPROM”. Now this company is developing and introducing different local systems of diagnostics: a noise diagnostics system (NDS), regime diagnostics system (RDS), dynamic diagnostics system (DDS), and emergency diagnostics system (EDS). The complex of such systems based on the common ideology of the reactor operative diagnostics, which interacts with regular monitoring and control systems of the reactor installation, is capable to provide both completeness and depth of diagnostics that meets the modern requirements for safe maintenance of an NPP.

The NDS operates only if a reactor is in stationary state, uses the fluctuating part of a signal, and due to its sharp response to anomalies it is aimed mainly at the detection of faults at the earliest stages of their development when they still have not been shown at all in the deterministic signals of regular detectors.

The NDS has the developed pre-computer electronics (analogue and digital) that processes rather weak signals in comparison with their constant components. According to methods for noise diagnostics, the NDS can be subdivided into systems of signature diagnostics and diagnostic systems on a physical level.

Signature noise diagnostics does not require comprehensive physical interpretation of noise performances and is based on continuous comparison of the current probability characteristics with the pre-estimated references.

Another trend, the noise diagnostics on the physical level is based on the analytical description of noise images or, at least, on the analytical description of dominating sources. It allows the noise image to be presented in the terms of physical properties, more often not measured regularly (reactivity coefficients, thermo-hydraulic parameters of the active region and separate sections of circuits, characteristic frequencies of vibrations of in-housing components, mode of oscillations of the reactor housing, etc.). Their continuous estimation by noise channels improves an observability of the object and carries the information not only about the fact of the fault origin but also about its localization and reasons of the origin.

The RDS and DDS are the systems that analyze signals of regular detectors with the purpose of assessment of the current technical condition. The RDS functions only under steady conditions, diagnostics in transient regimes are carried out by another system - DDS, and the continuity of diagnostics is achieved by the integration of the RDS and DDS.

The RDS is realized on the basis of a logical diagnostic model, taking into account features of the reactor as an object of diagnostics (availability of the own feedbacks and actions of automatic controllers). Diagnosing is carried out according to the graphs of faults - time sequences of falls of diagnostic signs outside the assigned limits. The RDS performs early diagnostics prior to fall of any signal outside the regular preventive setting. The RDS is capable of diagnosing a reactor installation with the indistinctly formalized images of faults. The self-diagnostics of detectors is carried out by function links and balance relations intrinsic to the given reactor installation.

The RDS is:

- a system of functional diagnostics identifying the technical condition of a reactor installation without specially organized test effects, in regular operation modes of the reactor, and with the regular detection equipment;
- an “on-line”, “real-time”, all-mode, independent, continuously operated system, not requiring control of the diagnosing process on the part of the operator, with automatic setting of diagnosis;

- a system of early diagnosing;
- an adjustable system open for changes in the number of information channels, diagnostic signs, diagnosed situations, modes of diagnosing, depth of memory, value of diagnostic thresholds, and time step of diagnosing;
- a self-protected system against “indistinct” knowledge of experts, keeping the initial quality of diagnosing even under detector failures;
- a system producing self-diagnostics of detectors;
- a system forecasting a technical condition of the reactor after the detection of anomalies.

The DDS is based on an analytical model of the object dynamics. In the ideal case, such models are real-time references, with which the current transient state of the object is compared at any moment. The continuous monitoring of a difference between measured signals of the object and signals of a dynamic standard model allows the diagnostics task “to be fixed”. Thus, the DDS can be present as a collection of reference and RDS models.

The emergency diagnostics system (EDS) starts evaluating the technical condition of the object after the activation of emergency protection (EP). The EDS operation results in the detection of reasons of the EP activation, prediction of accident evolution, advices on management of the out-of-order object, control of emergency automatic procedures, control of safety systems operation, archiving of emergency transients, diagnostics of detectors. Post-emergency diagnostics, which defines the stationary state of the object on completion of all emergency transients, is the EDS function as well.

The complex diagnostics system (CDS) integrates different systems of diagnostics. Its creation has solved the problems originating in attempt to design a diagnostic model that describes all stages of developing failures of a reactor installation. For early diagnostics it is important to detect a fault at a stage of its origin; therefore, the sensitivity properties of the diagnostic model are more important than its localizing properties.

On the contrary, during diagnostics of the object being in the emergency state, when the fault has been shown in signals of many detectors and the problem of its detection has been resolved, the diagnostic model should precisely find a cause, localize and predict a fault. At different time stages of its development, the compromise between the enumerated competing factors is necessary.

The CDS uses information from the NDS, RDS, DDS, and ADS. This information is represented in the CDS as balance relations, which describe the service capability of the reactor installation as a whole:

- balance of mass (consumption) for detecting leaks of the coolant and faults associated with redistribution of the coolant flow;
- balance of energy (power) for detection of faults bound with change in an efficiency factor of a power installation;
- balance of reactivity for detection of faults connected with unauthorized perturbation of neutron power.

The change in value of the balance relation testifies the presence of faults. Their search is conducted by logical models only for those faults, which a priori result in the established upsetting of the balance.
Along with the diagnostics of the object, the task of diagnostics of detection equipment is solved. It is especially important for a reactor, which has a high degree of independence, as an object of diagnostics. The problem of diagnostics and the object as well as its detectors is incorrect; there is an element of a vicious circle here: the information flow generated for the object diagnostics is used as well for self-diagnostics of detectors causing this information flow. All ways of diagnosing the object and its detectors with the same information flow are based on the so-called detection redundancy included in a reactor design. The redundancy can be reached by backup of detectors, by functional and stochastic correlation of signals from different detectors because of correlations of physical processes in the object.

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ANNEX C.6.

REPLACEMENT OF THE REACTOR CONTROL AND PROTECTION SYSTEM IN UNIT 1 & 2 OF THE BEZNAU NUCLEAR POWER PLANT

C. Hangartner
NPP Beznau, Switzerland

1. ABSTRACT

The Beznau Nuclear Power Plant (KKB) consists of two identical units and is located in the lower Aare River valley. The plant has an electrical capacity of 760 MW and is operated by Nordostschweizerische Kraftwerke (NOK). Both units are pressurized-water reactors, each with two steam generators and two turbine sets. Unit 1 came on-line in 1969, and Unit 2 followed in 1971.

A programme of retrofitting and upgrading aimed at keeping the power plant up to date in terms of safety has been carried on with the replacement of the reactor control and protection system by a state-of-the-art computer-based system. The old safety control system, which had operated without malfunctions, had to be changed because the system supplier no longer provided technical support and thus no spare were available.

Project PRESSURE (the name is a German acronym meaning "reactor control and protection system replacement") went through several intensive phases, dating back to 1990. They included a number of feasibility studies and bid invitations to suppliers all over the world. The management of the project lies with a team of our own in-house engineers, who have not only special knowledge of control systems but also good knowledge of the processes in the existing plant. The replacement was successful. Since then both plants are in undisturbed operation.

2. PROTECTION SYSTEM REPLACEMENT

The first consideration for a replacement of the reactor control and protection system is dating back to 1990, when the supplier of the existing FOXBORO H-line system announced, that the support for this system would no longer be guaranteed. The main activities for the project started in 1994.

The project objective was a functional replacement of the reactor control and protection system in consideration of suitable interfaces, compliance with state-of-the-art requirements, no special outage for installation and commissioning and no change of the well-proved operation philosophy.

On this basis, 20 new cabinets replaced 41 cabinets. The cabinets for the four redundant reactor protection systems were placed in four separate rooms. The new reactor control and protection system is based on the digital I&C System TELEPERM XS.

The project was divided into four phases: the preliminary study (1), the pre-project (2), the main project (3) and the realization and implementation phase (4). In early 1998, after completion of phase 3, the contract for delivery, installation and commissioning of the reactor protection and control system by SIEMENS/KWU, meanwhile FRAMATOME ANP (FANP), was signed. A key factor of this decision was the conviction, that TELEPERM XS is the most qualified and future oriented system for functions important to safety in nuclear power plants.

The further project process included the two main activities, the design, manufacturing and test field activities and the approval activities. In all these activities, up to 20 persons of the KKB staff was included for design review, for installation and commissioning planning and for co-operation in the test facility. This co-operation had the advantage of an on the job training to get familiar with the new system.

At the end of September 1998, the formal request for the concept approval was submitted to the Swiss Nuclear Safety Inspectorate (HSK). During the approval process, which was terminated at the end of 1999, some modifications in the concept and the design were requested. The approval process was also characterized by an intensive correspondence between HSK and KKB as well as by several meetings.

After completion of comprehensive tests at the test facility, lasting from January until April 2000, the cabinets were shipped to Beznau where pre-installation work, e.g. cable routing and wiring had started in the meantime. The newly built space made it possible to install the cabinets for redundancies 2 and 4 even before plant shut down. Likewise, some early commissioning tests could be performed.

The shut down of unit 1 for the outage was on July 21 and the main activities for dismantling and installation started on July 29, after the reactor was unloaded. Reloading of the reactor began on September 16 and full power was reached on October 8.

The schedule for unit 2 was similar to unit 1. The outage started on July 13, 2001 and the main replacement activities on July 21. We reached full power on September 24. Since then the plant has been in an undisturbed operation.

ANNEX C.7.

I&C AGEING MANAGEMENT IN US NUCLEAR POWER PLANTS

H.M. Hashemian
Analysis and Measurement Services Corp., United States of America

1. ABSTRACT

There are 103 operating nuclear power plants in the USA, as of 2003. Most of these plants have already passed or are close to passing their mid-life of 20 years, as the licensed life of a nuclear power plant in the USA is 40 years. Over the last ten years, the economics of nuclear power plants in the USA has improved dramatically, and most plants have announced that they will apply for life extension to 60 years. In fact, as of February 2003, nearly ten nuclear power plants have already received or are in the process of receiving government approval for life extension to 60 years.

With life extension in full swing in the USA, the ageing questions have become more important. In fact, ageing is a significant issue in the U.S. nuclear power industry, and great efforts have been spent over the last two decades to address the ageing of all-important Systems, Structures, and Components (SSCs). As a result, a large volume of useful information and data has emerged on ageing characteristics of SSCs and on what can be done to manage the ageing process and cope with its consequences. In this paper, the relevant activities of I&C ageing management in the USA are summarized.

2. I&C AGEING MANAGEMENT

In the area of I&C, the ageing concerns are mostly focused on cables. This is evident from the great number of research projects sponsored over the last two decades by the U.S. Nuclear Regulatory Commission (NRC) and the U.S. Department of Energy (DOE) at the Sandia National Laboratory, Brookhaven National Laboratory, and elsewhere. Also, the Electric Power Research Institute (EPRI), National Institute of Standards and Technology (NIST), National Aeronautics and Space Administration (NASA), Department of Defense (DOD), and Department of Transportation (DOT) have conducted research programmes to understand the ageing characteristics of cables, including both the cable insulation materials and the conductor, and to develop cable condition monitoring techniques. The NRC organized a conference over the period of April 23 to 25, 2002, under the title “International Conference on Wire System Ageing.” The proceedings of this conference (NUREG/CP-0179) provides significant insight on the importance of cable ageing and the need for routine cable condition monitoring in the nuclear power industry. In particular, development of effective cable condition monitoring techniques for installed cables was identified in the NRC conference as an urgent need.

The main problem with ageing of cables is that the cable insulation material can become dry and brittle and fail, causing moisture intrusion in the cable, fire, and other problems. Fortunately, there are objective means to detect cable degradation and failure, thereby avoiding such consequences. This includes electrical measurements, mechanical measurements, chemical tests, and visual inspections. Some of these measurements require access to the cables or a sample of the cable for the test. It is for this reason that cable depots are used in the containment of nuclear power plants to induce natural ageing in samples that are then used to evaluate the condition of the installed cables. Most of the electrical tests can be performed in-situ. With the in-situ tests, a sample is not normally needed, and the tests can often be performed remotely from the control room area or cable spreading room while the plant is operating. For example, the Time Domain Reflectometry (TDR) test can be performed in-situ while the plant is operating to identify and locate problems such as increased areas of resistance in cables and connectors. The TDR test can also reveal problems about the cable insulation material.

In addition to the basic tests mentioned above, a great number of advanced techniques are under development or already available for testing of cables, especially for non-destructive testing. These include ultrasonic tests, thermography, Nuclear Magnetic Resonance (NMR) techniques, optical diagnosis, etc. A description of these and other cable testing techniques is given in NUREG/CP-0179, the proceedings of NRC's 2002 Conference on Wire System Ageing.

Neutron detector cables are of particular importance in nuclear power plants. In many occasions, flux measurement problems involving neutron detectors have been traced to cables. As such, testing of neutron detector cables is important. Core exit thermocouples are also prone to problems due to cables. Recently, a U.S. plant replaced a core exit thermocouple in response to a temperature measurement problem. However, the problem did not disappear with the thermocouple replacement. An investigation revealed that the problem was in the thermocouple cables and not in the thermocouple itself.

The ageing of I&C sensors, such as Resistance Temperature Detectors (RTDs), pressure, level, and flow transmitters have also been of concern. This is evident in ageing research projects that the NRC funded in the 1990's resulting in publications of a number of NRC reports including NUREG/CR-5560, NUREG/CR-5851, NUREG/CR-5383, NUREG/CR-5501, and others. These efforts have concluded that sensor ageing can be managed through periodic testing including calibration and response time testing. In fact, due to ageing concerns and regulatory requirements, new techniques have been developed in recent years to allow routine in-situ response time testing of sensors and on-line calibration verification. For example, the loop current step response (LCSR) technique was developed for in-situ response time testing of nuclear plant RTDs and the noise analysis technique was developed for in-situ response time testing of pressure transmitters. The noise analysis technique also identifies sensing line problems, such as blockages, which can cause the response time of a pressure sensing system to increase drastically. As for on-line calibration verification, the cross-calibration method has been developed for RTDs and the on-line monitoring approach has been developed for pressure transmitters. The details of these methods are presented in the references given at the end of this report.

Another sensor ageing issue in nuclear power plants is the degradation of core exit thermocouples in pressurized water reactors (PWRs) due to moisture intrusion through the sheath. This problem not only causes thermocouples to produce erratic reading, but also can allow radioactive water to diffuse into the sensor and find a way outside the pressure boundary. The latter is not only an I&C problem, but also a safety problem. This problem can be identified in-situ through measurement of insulation resistance, LCSR measurement, and cable testing.

In addition to ageing, obsolescence is a major I&C issue in the USA. Many I&C components in the U.S. plants come from only a few manufacturers. Due to the small size of the nuclear market, the components that are specific to nuclear power plants are sometimes removed from product lines and no longer produced. This places a tremendous burden on the nuclear industry to find replacement parts.

In recent years, digital I&C equipment has become prevalent in the nuclear power industry. The digital I&C products have been very useful to the industry, but the obsolescence problem is a greater concern with digital equipment compared to the old analog equipment. Almost all digital I&C products are upgraded on a frequent basis. Thus, obsolescence is a big problem with digital equipment.

There is not much data available on the ageing characteristics of digital I&C equipment, as this equipment has only been used in nuclear power plants over the last decade. What is known of the digital I&C equipment is their subtle failures and the fear of common mode problems. In fact, common mode failure concerns and the software validation and verification (V&V) issues have been at the center of debate as to whether or not to use digital I&C equipment in critical systems in nuclear power plants. This is aside from the obsolescence and ageing concerns.

The IAEA TECDOC-1147 (June 2000) provides additional useful information on ageing of I&C equipment in nuclear power plants and how the I&C ageing may be managed.

Two databases are maintained in USA to track the performance of important plant equipment including I&C. These databases are referred to as Licensee Event Report (LER) database that is maintained by the NRC, and the Nuclear Plant Reliability Data System (NPRDS) database that is maintained by the nuclear power industry. These databases are very useful in determining if there are components in nuclear power plants that suffer from a common problem. Both the LER and NPRDS databases have been used to provide data on ageing degradation and failure of I&C equipment. In fact, a number of ageing research projects have focused on analysis of LER and NPRDS databases to arrive at information on ageing characteristics of key components in nuclear power plants.

Among other related developments in the USA is the "maintenance rule" that went into effect in 1996. The maintenance rule requires nuclear power plants to track the performance of equipment, including process instrumentation, to identify the onset of failures. The maintenance rule was published as a U.S. government document called 10CFR50.65, "Requirements for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants".

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CONTRIBUTORS TO DRAFTING AND REVIEW

Bock, H.W.	Framatome ANP GmbH NLL, Germany
Burgis, R.	AECL, Canada
Eiler, J.	Paks NPP, Hungary
Hashemian, H.M.	Analysis and Measurement Services Corporation (AMS), United States of America
Kim, K.H.	Korea Nuclear Instrumentation and Control R&D Centre, Republic of Korea
Kononenko, A.I.	Research Institute of Scientific Instruments, Russian Federation
Manners, S.	Institute de Radioprotection et de Sûreté Nucléaire (IRSN), France
Thoma, K.	Nordostschweizerische Kraftwerke, Kernkraftwerk Beznau, Switzerland
Yamamoto, T.	Japan Power Engineering and Inspection Corporation, Japan

Consultancy Meeting

Vienna, Austria: 24–27 September 2002

Advisory Group Meeting

Vienna, Austria: 5–8 May 2003