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# MANAGEMENT OF I&C AGEING

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**Abstract**

This country report is based on data collected within working committees of VGB Technical Association of Large Power Plant Operators, Essen, Germany, namely the report „Ageing Diagnosis, Prediction and Substitute Strategies for I&C" by R. Heinbuch, J. Irlbeck (Bayemwerk Kernenergie AG München) and W. Bastl (Institut für Sicherheitstechnologie GmbH Garching). It was compiled in its current form by L. Mohrbach, VGB Headquarters, in his capacity as member of the IAEA Advisory Group on Nuclear Power Plant I&C Equipment: Periodical Testing, Evaluation and Maintenance Strategy.

## 1. INTRODUCTION

The operators of nuclear power plants in Germany follow different strategies for the maintenance of instrumentation and control (I&C) technology in their plants, including replacement. Basic tasks and goals of the management of ageing are the diagnosis of inadmissible changes of system characteristics and the provision of the required spare parts and replacement deliveries, taking into consideration operating experience and innovative progress. Key topics in this field are qualification for accident conditions, change-over to computer- based digital I&C or alternative solutions like e.g. replacement by application specific integrated circuits (ASICs).

The nineteen nuclear power plants that are in operation today (1998) in Germany were commissioned between 1968 and 1989. Since then, several I&C generations were developed by the industry, all of which are used in the power plants today. In the first generations, fixed- wired electronic systems in discrete semiconductor technology were applied, supplemented by process computer based information systems. Today, I&C for conventional and for nuclear power plants, be it new construction or replacement, is principally being realized in digital technology. This applies also for the I&C systems with safety relevance of nuclear power plants, both domestically (replacement) and for export projects (replacement and new construction). The manufacturing industry has announced that this technology will be favored in future, leaving the analog I&C systems with increasingly less supplier support.

The proof of functioning of the operational and safety relevant I&C is ensured by extensive repetitive tests. With these tests it was assumed until now that the proof for resistance to accidents, namely the loss-of-coolant accident (LOCA), attained at the plant erection within the frame of the type tests with timelapsing ageing simulation, wouldn't have to be repeated for the remaining life-span of the components.

In the last years extensive discussions and investigations have taken place about the period of confidence for the original accident resistance proof test. The results are laid down in KTA Safety Standard draft 3706 (June 13, 1994). The paper describes the requirements for the repetitive proof of the LOCA resistance of safety system I&C components.

The experience gained from the renewal of these systems is described by concrete examples. The important results are an improvement of the man- machine interface and of system and overall plant availability.

Furthermore, running old I&C technology reliably and securing the delivery of suitable replacement systems are defined as the basic tasks of the management of ageing.

## 2. PRESENT SITUATION

In an increasing number of cases the original I&C components are not produced any more. The supply of replacement parts, if not taken from stock, can today only be assured by expensive special production runs. These again live from a stock of discrete components (transistors, diodes, etc.) which is not refilled anymore. Only in some cases pin- compatible new generation components are on the market. The availability of spare parts is therefore in principle endangered and the arising costs thereof are not predictable anymore.

Ageing effects can be observed in the older plants (drift phenomena, electrolyte capacitors). The failure rates still lie within the normal range. Only until recently the maintenance measures needed for the securing of function could still be performed with reasonable expenditure in the old technology.

The exchange of the I&C systems will be necessary up to three times during the life-span of a power plant. Replacement actions are currently performed and their number is increasing. For I&C expansions in the operational and in safety relevant areas, computer based digital I&C systems are basically being engaged today. The market for suitable new I&C systems is expected to grow significantly, thus enabling further safe and reliable operation of the power plants.

## 3. PROOF OF FUNCTION, PERIODICAL TESTING

Qualification, quality assurance and proof of the required functional capabilities of electrical and I&C components is performed during manufacture, assembly and commissioning. The preservation of these characteristics is being proven by periodical testing, which is carried out either during operation or shutdown of the plant.

These tests require a relatively large personnel effort, if testing has to be performed manually. So, as far as possible, automatic testing equipment, namely computerized test devices are used, which fulfill high quality requirements. Of course, special attention is paid to the software.

## 4. PROOF OF ACCIDENT RESISTANCE

Safety relevant I&C components must be qualified for accident situations, notwithstanding ageing. Complete repetitive test for the preservation of performance under accident conditions on the built- in components are in general not possible for obvious reasons. Therefore the following measures had to be taken in order to achieve the long-term accident resistance of electrical and I&C components within the frame of the plant specifications:

- selection of suitable materials with regard to the expected operational temperature and radiological dose rate at the installation sites;
- design reserves in terms of mechanical stability and humidity protection;
- type and suitability tests on artificially pre-aged specimens.

An essential part of the type tests is the experimental reproduction of the stress under accident conditions on specimens. Test curves have been defined on the basis of LOCA simulations as realistic as possible.

Especially for plastics it has not been possible to achieve theoretical ageing predictions. Pre-ageing for the simulation of 40 years of reactor operation had to be applied. Acceleration factors of 40 for thermal and radiological pre-ageing have even proven to be too large for the prediction of the age-dependent decomposition of synthetics, mainly because the oxidation process cannot be simulated realistically enough in this short period.

For all these reasons the continued resistance to accident conditions of the I&C components must be secured during operation with other means. A basic accident proof design in the sense of the above mentioned measures remains as prerequisite.

## 5. PRESERVATION OF ACCIDENT RESISTANCE

In order to evaluate the accident resistance of I&C systems, investigations concentrated on components regarded as most susceptible to ageing. In general LOCA resistance is secured by a three-step approach, starting with theoretical investigations, tests (sometimes as part of the prescribed component revisions), and - where necessary - component exchange. Some examples are given below:

1. Inspections were recently performed for actuators of older plants, especially for valve positioners and magnetic positioners in general, including their cabling, plugs, terminals and containment penetrations. Recurrent testing is obligatory for these components every eight years. Initial findings revealed a need for extra qualification of older components. For economic reasons all components in question were exchanged with improved designs, dismissing the need for further investigations.

Under this revision also the housings of accident proof switches were tested on-site for leaks. On detection of undue leaks, cable connections including grouting were changed according to component specification. Long-term operation will now be possible, as long as the availability of the positioners and subparts can be secured under reasonable conditions.

2. For electric motors in the annulus outside of the containment, theoretical investigations have shown that no undue shortening of life of the windings had to be expected under the anticipated temperature rise in the annulus during a LOCA.
3. A third example dealt with the transducers of the reactor safety instrumentation. Investigations have shown that replacement is here the preferable option. The advanced age of the mechanical gauges and electrolytic capacitors was the driving reason for this exchange.
4. For a particular cable type, a R&D programme of the manufacturer has revealed a noticeable, exposure dependent radiation dose effect. From special tests on pre-aged I&C cable specimens, adapted to simulate a representative ageing profile in the vicinity of the primary circuit, a LOCA limit dose rate function was established by the manufacturer. Subsequently all cables which were reaching their permissible operational radiation dose limit for LOCA resistance in locations near primary loops have been exchanged.
5. Tests on selected 61- pole resin cable penetrations carried out using realistic conditions for an anticipated accident course for a BWR gave a satisfactory seal tightness. Further tests with 4-pole resin penetrations are planned.

With the consecutive application of this three- step approach considerable LOCA resistance confidence periods can be guaranteed for all component generations. Proof for the preservation of accident stability must be given in any case in time before individual confidence periods expire.

Correct measurement of operational temperature and radiation exposure at the location of the individual component is important in order to allow an ageing evaluation. This can be performed through on-line dosimeters and maximum temperature recorders over a typical reactor cycle and subsequent extrapolation over past and future time spans.

## 6. RESEARCH AND DEVELOPMENT PROGRAMMES, NATIONAL STANDARDS

The above mentioned three- step LOCA resistance evaluation procedure, but also other reasons like ageing effects and shortcomings in the type tests have in practice led to the exchange of most of the original accident proof I&C components. This experience, however, does not contradict that certain electrical and I&C components can remain in use for periods which lie in the range of the life expectancy of the whole plant. An exchange of all accident proof cables or large components like motors is regularly not necessary because of the small accident stress.

For this reason, for equipment which is basically qualified as accident proof it seems appropriate to develop on- line monitoring procedures. A VGB technical committee is working in this field since 1988.

In parallel to this utility working team, a national standard KTA 3706 "Recurrent Proof of the Accident Resistance of Electrical and I&C Components of the Safety System" was completed. Besides of the already mentioned replacement option, two further paths are kept open in this KTA standard for proving the preservation of accident resistance, i.e. substitute tests and special tests.

In the course of the substitute tests, components for which LOCA resistance is required may also be tested locally by means of simulation procedures like spray- testing, dive-pressure tests, and others. Especially spray- tests on terminals were performed by the manufacturer on order of the VGB committee. The associated test procedure (VESPA) was assessed by TÜV Rheinland, acting as independent expert. Further substitute tests, according to KTA, are sealing and heating tests.

In the special tests, the relevant steps of type testing are repeated. Typically three or six specimens have to be taken from the plant to form a large enough sample.

In both procedures, care has to be taken on how to assure a large enough load precursor, either by testing in a shorter time span (substitute testing) or by application of additional artificial ageing.

According to KTA 3706, the point in time for the start of the recurring LOCA resistance tests has to be fixed for each nuclear power plant individually. Test instructions must be set up before the test begins and they must have been approved by independent experts. The testing strategies, relating to component groups which should be put down in the test instructions, are currently being specified by a VGB working group.

In another study TÜV Nord investigated the ageing phenomena and lifetime expectancy of electrical equipment of the safety system and of the accident instrumentation in nuclear facilities under operational conditions. Apart from exceptions no ageing relevant changes in the failure behavior of the investigated nuclear power plant components were identified. In conclusion the study pointed out that electronic components usually have an innovation cycle which is shorter than the residence time in the plant. It is planned to continue this project with the co-operation of the utilities.

## 7. STRATEGIES FOR MAINTENANCE AND RENEWAL OF I&C

Preservation of function of older I&C systems required a reasonable effort for all NPP operators in Germany. Taking decreasing spare part availability for the older I&C technology into account, foresight strategies had to be developed.

From a current view the following options can be identified in principle:

- keeping large spare part stocks and/ or special production runs for old I&C systems (current practice);
- substitution of old I&C by means of functionally equivalent („pin compatible") components of modern micro electronics technology (ASICs) (current practice where appropriate);
- substitution of analogue I&C systems with new digital systems for operational (=not safety relevant) systems (partially practised), and
- total replacement with digital I&C, i.e. including safety systems (digital systems for safety relevant I&C is not yet certified in the USA and other countries).

## 8. SPARE PART KEEPING AND SPECIAL PRODUCTION OF OLD I&C

This method is currently being practiced especially in the area of safety relevant I&C. Quality assurance of the manufacturers and record- keeping for failure statistics of the old I&C are intensively supported by common actions of the utilities within the framework of the VGB working groups "Qualification of Electrical and I&C Components" and "I&C Failure Statistics".
In spite of the fact that failure behavior is currently still normal, and that the delivery of spares is still assured to a large extent, most utilities regard the renewal of these systems in the old plants necessary in the medium term.

## 9. DIGITAL SAFETY SYSTEMS

Digital I&C for application in safety systems has been developed or is being developed in several countries. In Germany, Siemens/ Power Generation Group KWU has developed TELEPERM XS with the support of the German utilities, for the long-term replacement of analog safety relevant I&C systems, and TELEPERM XP for operational systems.

TABLE I. REFERENCE LIST FOR SIEMENS TELEPERM XP (FOR OPERATIONAL SYSTEMS) IN NPPs

| **Plant Name** | **Type** | **Country** | **System** | **Commissioning** |
|---|---|---|---|---|
| Grohnde | PWR | Germany | | 1996 |
| Neckar-1 | PWR | Germany | Water Clearing | 1996 |
| Muehleberg | BWR | Switzerland | | 1996 |
| Borssele | PWR | Netherlands | Comprehensive I&C Retrofit | 1998 |
| St. M. de Garona | BWR | Spain | Cooling Water Clearing<br>Condensate Filter System | 1998 |
| FRM-II Garching | Research | Germany | | 2000 |
| Mochovce-1 and -2 | WWER | Slovakia | Complete I&C | 1998 - 1999 |
| Lianyungang-1, -2 | WWER | China | Complete I&C | 2004 - 2005 |

An assessment of the TELEPERM XS system for safety relevant I&C performed by Gesellschaft für Anlagen- und Reaktorsicherheit GRS has confirmed its suitability for use in nuclear facilities under highest safety demands.

For the PWR plants Neckarwestheim-1 and Unterweser, reactor limitation systems, reactor power control systems and control rod I&C systems have been replaced in 1997 and 1998. The technical specifications for these systems have formed the basis for the licensing procedure. TELEPERM XS will also be applied for the reactor trip system and neutron flux measurement for the new high flux research reactor FRM-2 at Garching.

Furthermore, TELEPERM XS has or will be installed for various safety systems in 19 other reactors in eight other countries.

Type-testing of the system components and the software of TELEPERM XS has been completed in 1995. For these particular tests, the basic requirements for traditional systems (as laid down in the KTA rules) were adapted. These rules require theoretical checks, e.g. in terms of functional description, specification, load, and practical checks e.g. in terms of functionality, electromagnetic compatibility and environmental conditions.

TABLE II. REFERENCE LIST FOR SIEMENS TELEPERM XS (FOR SAFETY RELEVANT SYSTEMS)

| **Plant Name** | **Type** | **Country** | **System** | **Commissioning** |
|---|---|---|---|---|
| Muehleberg | BWR | Switzerland | Level Monitoring System | 1995 |
| St. M. de Garona | BWR | Spain | Rod Control System<br>Rod Position Measurement | 1996 |
| Borssele | PWR | Netherlands | Comprehensive I&C Retrofit | 1998 |
| Unterweser | PWR | Germany | Reactor Limitation System<br>Reactor Power Control<br>Rod Control System | 1997 |
| Neckar-1 | PWR | Germany | Reactor Limitation System<br>Reactor Power Control<br>Rod Control System | 1998 |
| Oskarshamn-1 | BWR | Sweden | Neutron Flux Measurement | 1998 |
| Forsmark-3 | BWR | Sweden | Rod Control system | 1998 |
| Mochovce-1 and -2 | WWER | Slovakia | Complete I&C | 1998 - 1999 |
| Bohunice-1 and -2 | WWER | Slovakia | Reactor Trip system<br>Reactor Limitation System<br>Reactor Power Control<br>Neutron Flux Measurement<br>Engineered Safety Feature Actuation System | 1998 - 1999 |
| Paks-1 to -4 | WWER | Hungary | Reactor Trip system<br>Reactor Limitation System<br>Neutron Flux Measurement<br>Engineered Safety Feature Actuation System | 1999 - 2002 |
| Rovno-4 | WWER | Ukraine | Reactor Trip system<br>Reactor Limitation System<br>Neutron Flux Measurement | 2000 |
| Chmelnitzki-1 | WWER | Ukraine | Reactor Trip system<br>Reactor Limitation System<br>Reactor Power Control<br>Neutron Flux Measurement | |
| Beznau-1 and -2 | PWR | Switzerland | Reactor Trip system<br>Reactor Power Control<br>Emergency Feedwater System | 1999 - 2001 |
| FRM-II Garching | Re-search | Germany | Reactor Trip System<br>Neutron Flux Measurement | 2001 |
| Lianyungang-1, -2 | WWER | China | Complete I&C | 2004 - 2005 |
| Atucha-1 | HPWR | Argentina | Second Heat Sink | Study |
| Forsmark-3 | BWR | Sweden | Comprehensive I&C Retrofit | Study |
| Philippsburg-1 | BWR | Germany | Reactor Trip System<br>Rod Sequencing Calculation<br>Local Core Area Monitoring | Study |
| Biblis-A and -B | PWR | Germany | Reactor Limitation System<br>Reactor Power Control<br>Rod Control System | Study |

Likewise, type- testing has been applied to the new digital system. This was possible because:

- the system (regardless of its specific application) consists of modular hard- and software components;
- the system utilizes standardized software components, configurable to plant specific needs, and
- hard- and software interfaces can be described precisely and completely.

For software components, the following analyses have been performed:

- assessment of the development process and its measures for quality assurance;
- development from terms of reference over software specification, design, implementation to the code;
- verification of software interfaces;
- conformity with standards, mainly IEC 880;
- conformity with project internal guidelines, and
- assessment of failure and error analysis.

Finally, a system type test is performed upon commissioning to check the typical system properties:

- function;
- operational behaviour;
- no feedback of functions with respect to other functions;
- dynamic behaviour;
- reproducibility;
- maintenance and diagnostic properties;
- tolerable stress and failure behaviour;
- failure and error tolerance, and
- independence of the I&C system from the technical process (resistance to input data overload).

## 10. REPLACEMENT OF I&C COMPONENTS BY FUNCTION EQUIVALENT CIRCUITS (ASICs)

The development of micro- electronics has led to revolutionary changes in the production of electronic systems. Today a large amount of functions can be concentrated monolithically on an integrated circuit, in contrast to old I&C, where discrete parts (transistors, diodes, resistors, capacitors) had to be put onto printed circuit boards. The use of these pin- compatible Application Specific Integrated Circuits (ASICs) can be another solution for the replacement of old I&C.

The application of ASICs offers the following basic perspectives:

in terms of safety:

- the proven fixed structures remain;
- parallel signal processing;
- optimal protection against unintentional changes;

— high degree of integration (therefore fewer contacts);

— design and testing tools proven in mass fabrication;

— reduced software problems because only basic procedures of automation theory are needed during design;

in terms of functionality:

— all required analogue and binary signal functions can be realized;

— direct interface to digital processing possible;

— the test logic can be integrated directly onto the chip;

— high function density and consequently a small volume;

in terms of compatibility/ flexibility:

— pin-compatibility;

— flexibility for the protection function at planning stage can be ensured by design tools.

The VGB Working Group "I&C in Nuclear Power Plants" has initiated pilot tests of ASICs to replace old instrumentation and control systems. It is expected that qualification requires less effort in relation to software solutions.

## 11. IMPROVEMENT OF PERFORMANCE THROUGH NEW I&C

A system can be obsolete in spite of still fulfilling the originally specified properties. This is especially true for areas where much more powerful systems have become available and an improvement of plant safety or plant availability can be achieved.

The following measures (already taken in several German NPPS) can serve as examples for such improvements:

— plant process computers have been exchanged and extended in most plants, improving the man-machine interface, event diagnosis and expanding the extent and comprehensiveness of information;

— refuelling platform I&C systems have been refurbished, improving the functionality and the man- machine interface, thus contributing to minimize fuel outages;

— turbine I&C has been updated with the aim of improving the availability and the man- machine interface.

## 12. SUMMARY

The main goals for the management of ageing of electrical and I&C technology in nuclear power plants lie in the long-term preservation of function, taking into account technical development, operating experience and availability of spare parts in the future.

Long- term function is proven by repetitive testing. Safety relevant I&C components have to fulfill accident resistance criteria additionally. In extended research and development programs, solutions have been achieved which have been taken up in the KTA rule 3706.

TABLE III. LIST OF RELEVANT KTA RULES

| Safety Standard | Title | Status (Date of Issue) | English Transl. | Reaff. |
|---|---|---|---|---|
| KTA 1202 | Requirements for the Testing manual | R (8/84) | av. | 1994 |
| KTA1404 | Documentation During the Construction and Operation of Nuclear Power Plants | R (6/89) | av. | 1994 |
| KTA 1501 | Stationary System for Monitoring Area Dose Rates within Nuclear Power Plants | R (6/91) | | 1996 |
| KTA 1502.1 | Monitoring Radioactivity in the Inner Atmosphere of Nuclear Power Plants; Part 1: Nuclear Power Plants with Light Water Reactors | R (6/86) | av. | 1996 |
| KTA 3403 | Cable Penetrations through the Reactor Containment Vessel | R (10/80) | av. | 1996 |
| KTA 3501 | Reactor Protection System and Monitoring Equipment of the Safety System | R (5/85) | av. | 1995 |
| KTA 3502 | Incident Instrumentation | R (11/84) | av. | 1989 |
| KTA 3503 | Type Testing of Electrical Modules for the Reactor Protection System | R (11/86) | | 1997 |
| KTA 3504 | Electrical Drives of the Safety System in Nuclear Power Plants | R (9/88) | | 1993 |
| KTA 3505 | Type Testing of measuring Transmitters and Transducers of the Reactor Protection System | R (11/94) | av. | 1997 |
| KTA 3506 | Tests and Inspections of the Instrumentation and Control Equipment of the Safety System of Nuclear Power Plants | R (11/84) | av. | 1997 |
| KTA 3507 | Factory Tests, Post-Repair Tests and Demonstration of Successful Service for the Instrumentation and Control Equipment of the Safety System | R (11/86) | av. | 1996 |
| KTA 3701 | General Requirements for the Electrical Power Supply in Nuclear Power Plants | R (6/97) | | |
| KTA 3703 | Emergency Power Generating Facilities with Batteries and Rectifier Units in Nuclear Power Plants | R (6/86) | av. | 1992 |
| KTA 3704 | Emergency Power Facilities with Rotary Converters and Static Inverters in Nuclear Power Plants | R (6/84) | av. | 1994 |
| KTA 3705 | Switchgear Facilities, Transformers and Distribution Networks for the Electrical Power Supply of the Safety System in Nuclear Power Plants | R 9/88 | av. | 1993 |
| KTA 3706 | Repeating Proof of Coolant Loss-Breakdown Resistance of Electrical and Instrumentation and Control Components of the Safety Systems | R (8/94) | | |
| KTA 3901 | Communication Devices for Nuclear Power Plants | R (3/81) | av. | 1996 |
| KTA 3904 | Control Room, Emergency Control Room and Local Control Stations in Nuclear Power Plants | R (9/98) | av. | 1993 |

Mainly for reasons of spare parts availability, strategies for the replacement of old I&C systems are required. The tendency is to replace old I&C technology in the area of both operational and safety relevant I&C systems with digital systems.

The new digital safety I&C technology requires, like any computer based system, a high degree of formality to describe the process relevant demands. When defining these demands, experience and latest developments can be used for improvements.

On the other hand formal descriptions and their qualification require a high effort. ASICs offer an alternative here.

Today the new I&C technology contributes essentially to the improvement of plant performance, e.g. with regard to the man- machine interface and the diagnostic capabilities.

Table III is a list of German KTA standards which are relevant to the ageing management of I&C systems: