An Overview of IEC Activities on Instrument Condition Monitoring for NPPs

Pave The Road Towards Condition Based Qualification

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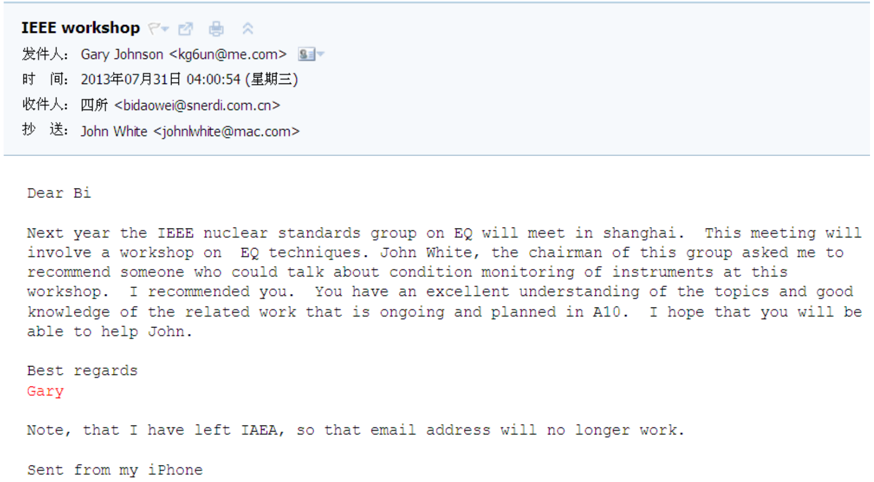
Topics to be presented

- Background
- Structure and scope of IEC TC45
- Brief review of condition based qualification
- IEC standards pertinent to condition monitoring
- Condition monitoring methods for instruments
- Comparison of CMs for cables and instruments
- Summary and recommendation

Backgrounds

- Coincidentally, an email from US inspired me to make this report on behalf of IEC in a workshop hosted by my own company.



IEEE workshop

发件人： Gary Johnson <kg6un@me.com>

时　间： 2013年07月31日 04:00:54 (星期三)

收件人： 四所 <bidaowei@snerdi.com.cn>

抄　送： John White <johnlwhite@mac.com>

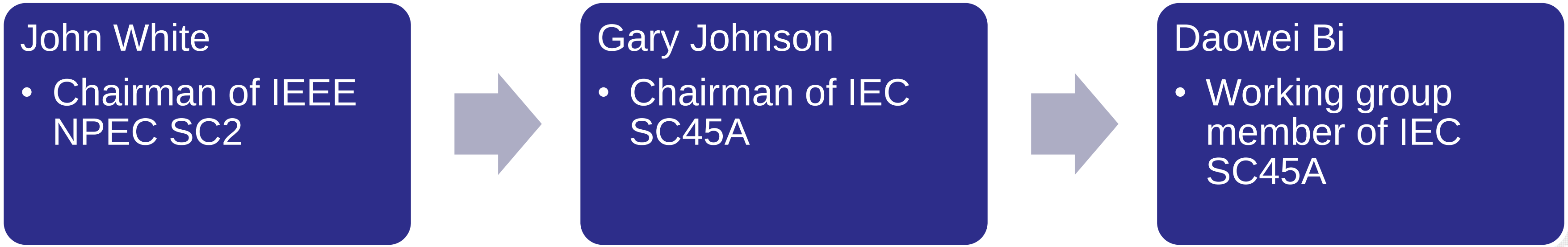
Dear Bi

Next year the IEEE nuclear standards group on EQ will meet in shanghai. This meeting will involve a workshop on EQ techniques. John White, the chairman of this group asked me to recommend someone who could talk about condition monitoring of instruments at this workshop. I recommended you. You have an excellent understanding of the topics and good knowledge of the related work that is ongoing and planned in A10. I hope that you will be able to help John.

Best regards
Gary

Note, that I have left IAEA, so that email address will no longer work.

Sent from my iPhone



John White
- Chairman of IEEE NPEC SC2

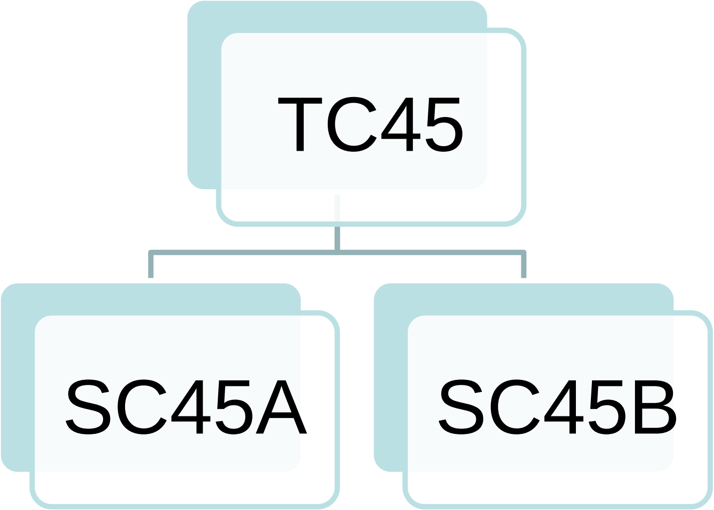
Gary Johnson
- Chairman of IEC SC45A

Daowei Bi
- Working group member of IEC SC45A

Structure and scope of IEC TC45

Structure of IEC TC45

- TC 45 Nuclear instrumentation



Subcommittees	
SC 45A	Instrumentation and control of nuclear facilities
SC 45B	Radiation protection instrumentation

Scopes of IEC TC45 and its Sub-Committees

- TC45
  - Established in 1959, produces and maintains standards for instrumentation, systems and equipment for many nuclear applications including,
    - nuclear energy and the nuclear fuel cycle, industrial and commercial uses of ionizing radiation, safeguarding special nuclear materials, and environmental and radiation protection.
  - TC 45 is responsible for the standardization of nuclear instrumentation that includes relevant terminology and classification, detectors of ionizing radiations and systems based on these detectors and the commercial applications of nuclear instrumentation technologies.
  - According to the TC45/IAEA agreement, our nuclear sector safety standards implement principles and terminology of the IAEA safety guides.

Scopes of IEC TC45 and its Sub-Committees

- SC45A
  - Responsible for the standardization of activities related to electronic and electrical functions and associated systems and equipment used in instrumentation and control (I&C) systems and electrical systems of nuclear facilities.
  - These activities include nuclear power plants, the entire nuclear fuel cycle from mining to processing, reprocessing, and interim and final repositories for spent fuel and nuclear waste.

Organization of IEC SC45A

Working Group	Description	Creation Date
WG 2	Sensors and Measurement Techniques	2008-07-25
WG 3	Application of digital processors to safety in nuclear power plants	2008-07-25
WG 5	Special process measurement and radiation monitoring	2008-07-25
WG 7	Reliability of electrical equipment in reactor safety systems	2008-07-25
WG 8	Control rooms	2008-07-25
WG 9	Instrumentation systems	2008-07-25
WG 10	Upgrading and modernization of I&C systems in NPP	2008-07-25
WG 11	Electrical systems	2013-01-14

Scopes of IEC TC45 and its Sub-Committees

- SC45B
  - Responsible for standardization activities covering all aspects of radiation protection instrumentation, including that for the measurement under both normal and accident conditions of external and internal individual exposure and exposure rates, in the workplace, in effluents, the environment and including foodstuffs.
  - Also responsible for the development of standards that are applicable to the detection and identification of illicit trafficking of radioactive material.

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Brief review of condition based qualification

Condition Based Qualification for NPPs

- According to IEEE 323-2003, this standard states,
  - Condition monitoring may be used in place of a qualified life to determine if qualified equipment is suitable for further service.
  - Condition monitoring for equipment qualification purposes monitors one or more condition indicators to determine whether equipment remains in a qualified condition. The trend of the condition indicator is determined during the performance of age conditioning of the test specimen during qualification testing.
  - The condition indicator must be measurable, linked to the functional degradation of the qualified equipment, and have a consistent trend from unaged through the limit of the qualified pre-accident condition.
  - Condition monitoring may be used with or independently from the concept of qualified life.
  - As the qualified equipment approaches the end of its theoretical qualified life, periodic condition monitoring may be implemented to determine if actual aging is occurring at a slower rate, and if further qualified service is possible based on the condition monitoring results.

Qualified Condition VS. Qualified Life

- Lack of knowledge, uncertainty and limitation of applicability of laws for calculating qualified life from artificial accelerated ageing results in large uncertainty in the time which the artificial ageing in the initial qualification correspond to in field conditions.
- This leads to use of excessive conservatism and margins in determination of qualified life. The equipment will therefore normally be able to function in a DBE at a time which is considerably longer than its qualified life.
  - In exceptional cases, it may still be shorter.
  - In any case, there is a demand for following the actual ageing of the equipment by regular activities after installation.

Qualified Condition VS. Qualified Life

- Application of the concept of condition based qualification allows a direct follow-up of the degradation of the equipment in the field due to ageing and comparison with the level of degradation for which the initial qualification has verified that it will still meet its design requirements in a DBE.
- By this method, it may be possible to extend the qualified life beyond the value originally calculated from the initial qualification.

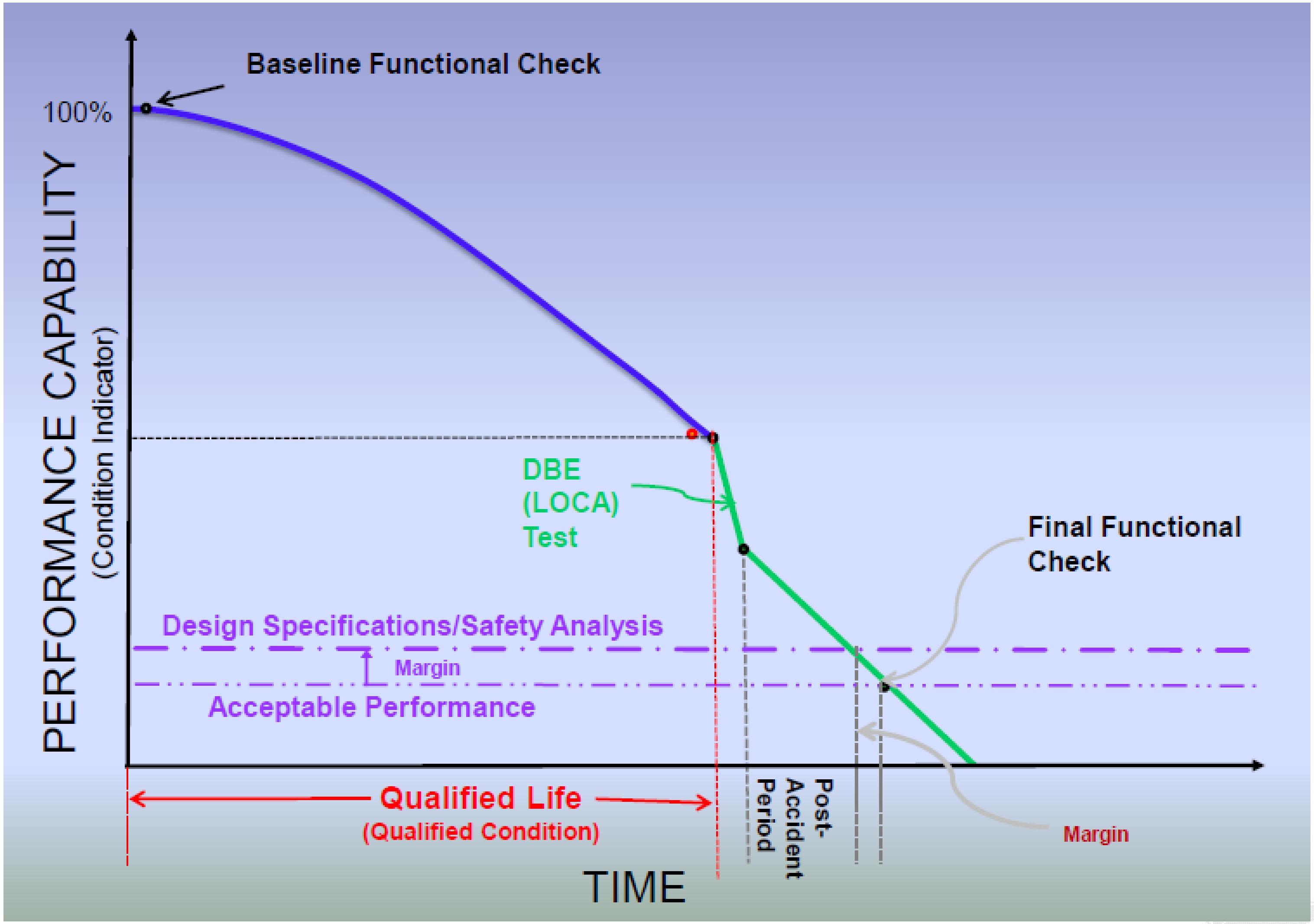
Qualified Condition VS. Qualified Life

- The qualified condition is established in the initial qualification by measuring one or more selected condition indicators during the artificial ageing.
- The value measured at the end of the artificial ageing is the qualified condition, provided that the ability of the artificially aged equipment to function according to its specification during DBE (and post-DBE if required) has been demonstrated.
- The establishment of qualified condition and relationship to qualified life is illustrated in Figure 3.4.

Commonly used qualification processes

- Visual inspection
- Measurement of initial functional properties
- Simulation of normal operational ageing
- Simulation of accident, post-accident period and functional verification
- Final properties measurement
- Final visual inspection

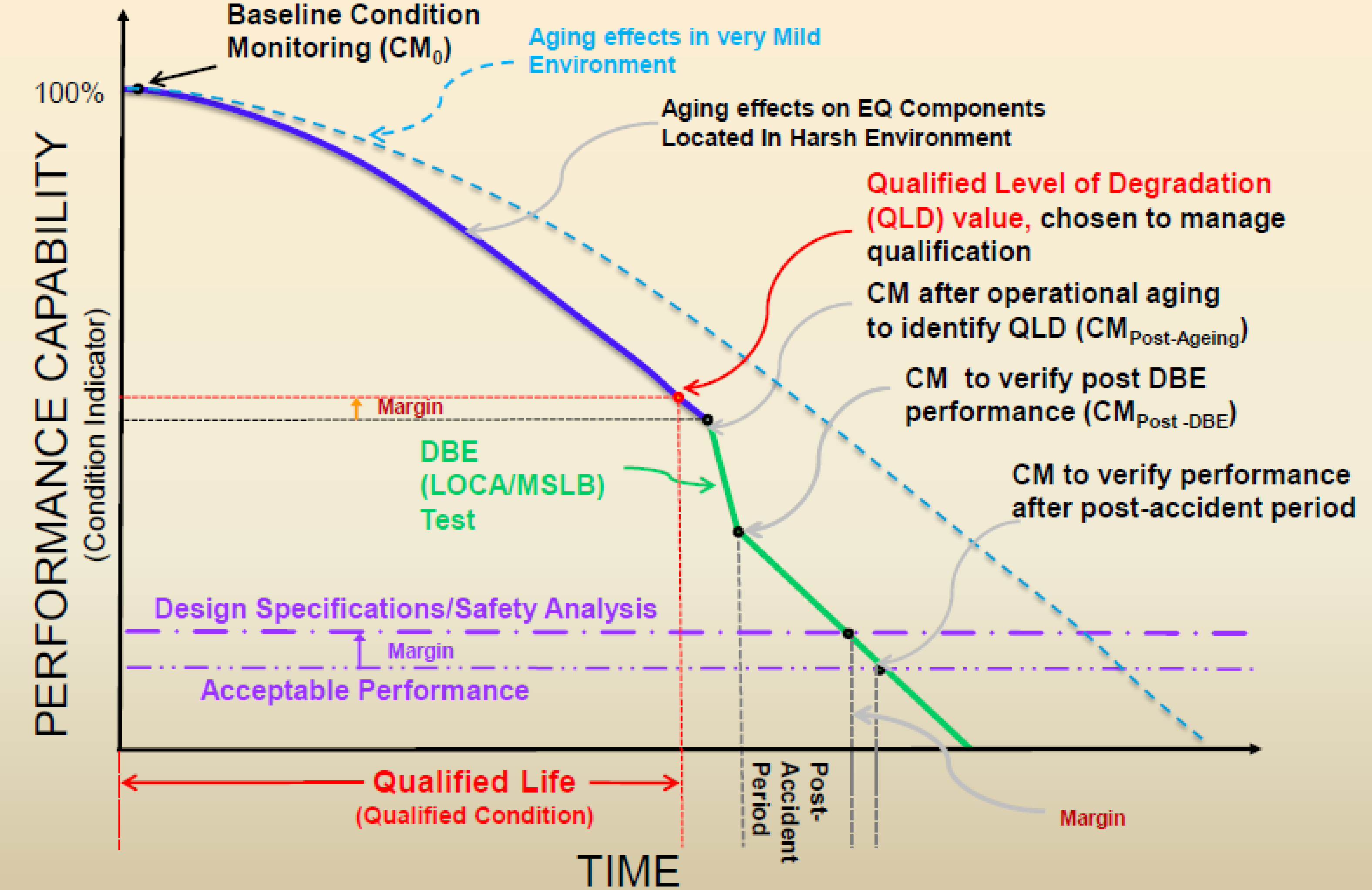
Commonly used qualification processes



Condition Based Qualification Processes

- Condition Based Qualification
  - During the qualification test, conduct condition monitoring of critical parameters before and after operational aging
  - Conduct the LOCA/accident environmental test and verify satisfactory performance again through condition monitoring
  - Identify the Qualified Level of Degradation (QLD) that the equipment can endure LOCA test
  - Manage the operational degradation to QLD with suitable condition monitoring (Regulatory Position 6, RG 1.211)

Condition Based Qualification Processes



Benefits of use of qualified condition

- Use of qualified condition solves the problem of depending on the laws for calculation of acceleration factors in artificial accelerated ageing and their parameter values, e.g. the activation energies, prediction of environmental conditions in the field (temperature, radiation dose rate, humidity, etc.), as well as synergism of combined environments. This means very substantial advantages for the management of ageing.
- However, use of qualified condition does not solve the issue of the effects of diffusion limited oxidation. This still has to be handled by collecting information on the materials involved and by applying moderate levels of the environmental parameters used for the artificial ageing.
- Vibration of polymers that have been subjected to thermal ageing or ageing in ionizing radiation can result in development of micro-cracks which can influence the dielectric behavior in DBE. Equipments in the reactor containment are normally not subjected to significant vibration. It should be noted, however, that condition monitoring methods do not normally react to micro-cracks in the polymers. Degradation of dielectric properties from having been subjected to vibration as part of the ageing only shows up at measurement in humid atmosphere, especially in DBE-conditions. It is therefore important to be aware of the risk of reduction of the ability of equipment which have been subjected to vibration, e.g. from external or internal events, at any time during its service life.

Selection of condition indicators

- When condition monitoring shall be included in the program for maintaining qualified life, it is necessary to:
  - identify condition indicators applicable to the equipment;
  - get information on how the values of these condition indicators change with ageing;
  - establish limit values on the condition indicators at which safe function in DBE is verified.
- The condition indicator selected for the qualified condition shall have a uniform trend with ageing time and be related to degradation of parameters of importance to the operability of the equipment.
- It is of some advantage if monitoring can be performed without affecting the equipment (non-destructive monitoring). This reduces the amount of work in connection with determination of changes with ageing, establishment of limit values and condition monitoring in the field.
- However, also destructive methods can be used.

Use of condition monitoring in the management of ageing

- Artificial testing in laboratory, performed with moderate acceleration factors and according to well-founded environmental prediction and test methods, gives a high degree of assurance that the equipment will function satisfactorily in normal operation, extreme operation and DBE for a limited installed time (qualified life). The uncertainty in life prediction and prediction of age related material degradation increases with installed time.
- Condition monitoring and inspections are tools to confirm that the ageing after a longer installed time has not proceeded at a higher rate than expected. Condition monitoring can be used to maintain and possibly extend qualified life and to ascertain that the equipment is not degraded to an extent above its qualified condition.
- When condition monitoring has been included in the qualification program, the initial qualification includes the following steps:
  - Identification, selection and measurement of condition indicators applicable to the equipment;
  - Recording the changes with time of the values of the condition indicators during the artificial ageing in the initial qualification;
  - Establishing the values of the condition indicators at the end of the artificial ageing before the function in DBE is verified.
- After installation, identical measurements of the selected condition indicators are carried out regularly on representative samples and the values are compared with the qualified condition.
- Inspections in connection with revision shutdowns form an important complement to condition monitoring. Such inspections can be used to identify areas with harsh environments (hot spots). Inspections can be useful for identification of environmentally induced degradation of cables and equipment, damage to thermal insulation of hot tubes, etc., that can aggravate hot-spots. The following observations on cables etc. can indicate hot-spots: discoloration, leakage of softeners, cracks in surface materials, hardening. Also observations in the surrounding structure (color changes, etc.) can indicate hotspots.

IEC standards pertinent to condition monitoring

SC45A standards on condition monitoring

- Continued efforts have been made within IEC community to develop and apply advanced condition monitoring techniques to enhance reliability and safety of nuclear power plant.
- IEC standard development activities in the following areas have enhanced industry awareness of the most up-to-date technological development.
  - Ageing management of cable systems
  - Ageing management of I&C systems, including transmitters
  - Electrical equipment condition monitoring methods
  - Performance assessment of instrumentation

Levels of condition monitoring

- As detailed in the preceding part, condition based qualification involves two categories:
  - Establishment of initial qualification
    - No such activity in IEC, as IEC 60780 do not include provisions related to condition based qualification
  - Maintain qualification status after installation
    - Extensive activities in this area, focusing on ageing management that incorporates condition monitoring as an effective and even preferred method to address ageing.

IEC standards incorporating Condition Monitoring for Ageing Management

Reference	Edition	Date	Title	Description
IEC 62342	Edition 1.0	2007-08-20	Nuclear power plants - Instrumentation and control systems important to safety - Management of ageing	Provides strategies, technical requirements, and recommendations for the management of ageing of nuclear power plant instrumentation and control systems and associated equipment. Also includes annexes on test methods, procedures, and technologies that may be used to verify proper operation of such equipment and aim to prevent ageing degradation from having any adverse impact on the plant safety, efficiency, or reliability. Applies to all types of nuclear power plants and relates primarily to safety.
IEC 62465	Edition 1.0	2010-05-11	Nuclear power plants - Instrumentation and control important to safety - Management of ageing of electrical cabling systems	IEC 62465:2010 provides strategies, technical requirements, and recommended practices for the management of normal ageing of cabling systems that are important to safety in nuclear power plants. The main requirements are presented in the body of this International Standard followed by a number of informative annexes with examples of cable testing techniques, procedures, and equipment that are available for the nuclear industry to use to ensure that ageing degradation will not impact plant safety. This publication contains colors which are considered to be useful for the correct understanding of its contents.

Condition Monitoring for Ageing Management

Project Reference	Title	Stage	Init. Date	Current Stage	Next Stage	Forecast Publication Date
IEC 62765 Ed. 1.0	Nuclear power plants - Instrumentation and control important to safety - Management of ageing of sensors and transmitters	CDM	2011-11	2013-05	2014-02	2014-12
IEC 62887 Ed. 1.0	Nuclear Power Plants - Instrumentation important to safety - Pressure transmitters	ANW	2013-08	2013-08	2014-03	2016-09

IEC/IEEE joint standards on condition monitoring methods (published)

Reference	Edition	Date	Title	Description
IEC/IEEE 62582-1	Edition 1.0	2011-08-31	Nuclear power plants - Instrumentation and control important to safety - Electrical equipment condition monitoring methods - Part 1: General	IEC/IEEE 62582-1:2011 contains requirements for application of the other parts of IEC/IEEE 62582 related to specific methods for condition monitoring in electrical equipment important to safety of nuclear power plants. It also includes requirements which are common to all methods.
IEC/IEEE 62582-2	Edition 1.0	2011-08-31	Nuclear power plants - Instrumentation and control important to safety - Electrical equipment condition monitoring methods - Part 2: Indenter modulus	IEC/IEEE 62582-2:2011 contains methods for condition monitoring of organic and polymeric materials in instrumentation and control systems using the indenter modulus technique in the detail necessary to produce accurate and reproducible measurements. It includes the requirements for the selection of samples, the measurement system and measurement conditions, and the reporting of the measurement results.
IEC/IEEE 62582-3	Edition 1.0	2012-12-12	Nuclear power plants - Instrumentation and control important to safety - Electrical equipment condition monitoring methods - Part 3: Elongation at break	IEC/IEEE 62582-3:2012 contains methods for condition monitoring of organic and polymeric materials in instrumentation and control systems using tensile elongation techniques in the detail necessary to produce accurate and reproducible measurements. It includes the requirements for selection of samples, the measurement system and conditions, and the reporting of the measurement results.
IEC/IEEE 62582-4	Edition 1.0	2011-08-31	Nuclear power plants - Instrumentation and control important to safety - Electrical equipment condition monitoring methods - Part 4: Oxidation induction techniques	IEC/IEEE 62582-4:2011 specifies methods for condition monitoring of organic and polymeric materials in instrumentation and control systems using oxidation induction techniques in the detail necessary to produce accurate and reproducible measurements. It includes the requirements for sample preparation, the measurement system and conditions, and the reporting of the measurement results.

IEC/IEEE joint standards on condition monitoring methods (in progress)

Project	Title	Stage	Init. Date	Current Stage	Next Stage	Forecast Publication Date
IEC/IEEE 62582-5 Ed. 1.0	Nuclear power plants - Instrumentation and control important to safety - Electrical equipment condition monitoring methods - Part 5: Optical time domain reflectometry (OTDR)	ACDV	2008-09	2013-03	2014-02	2015-06

IEC Project leader: Mr. SPANG (Sweden)
IEEE co-Project leader: Mr. GLEASON (US)

Performance assessment of instrumentation

Reference	Edition	Date	Title	Description
IEC 62385	Edition 1.0	2007-06-21	Nuclear power plants - Instrumentation and control important to safety - Methods for assessing the performance of safety system instrument channels	Defines the requirements for demonstrating acceptable performance of safety system instrument channels through response time testing, calibration verification, and other means. The same requirements may be adopted for demonstrating the acceptable performance of non-safety systems and other instrument channels.

Potential working items (PWI) in the future

- Additional condition monitoring standard (62582) on dielectric methods (dissipation factor)
- Additional condition monitoring standard on electrical methods (TDR, FDR, LIRA)
- Additional management of aging of sensors and transmitters standard (62765) (temperature, neutron flux, level)

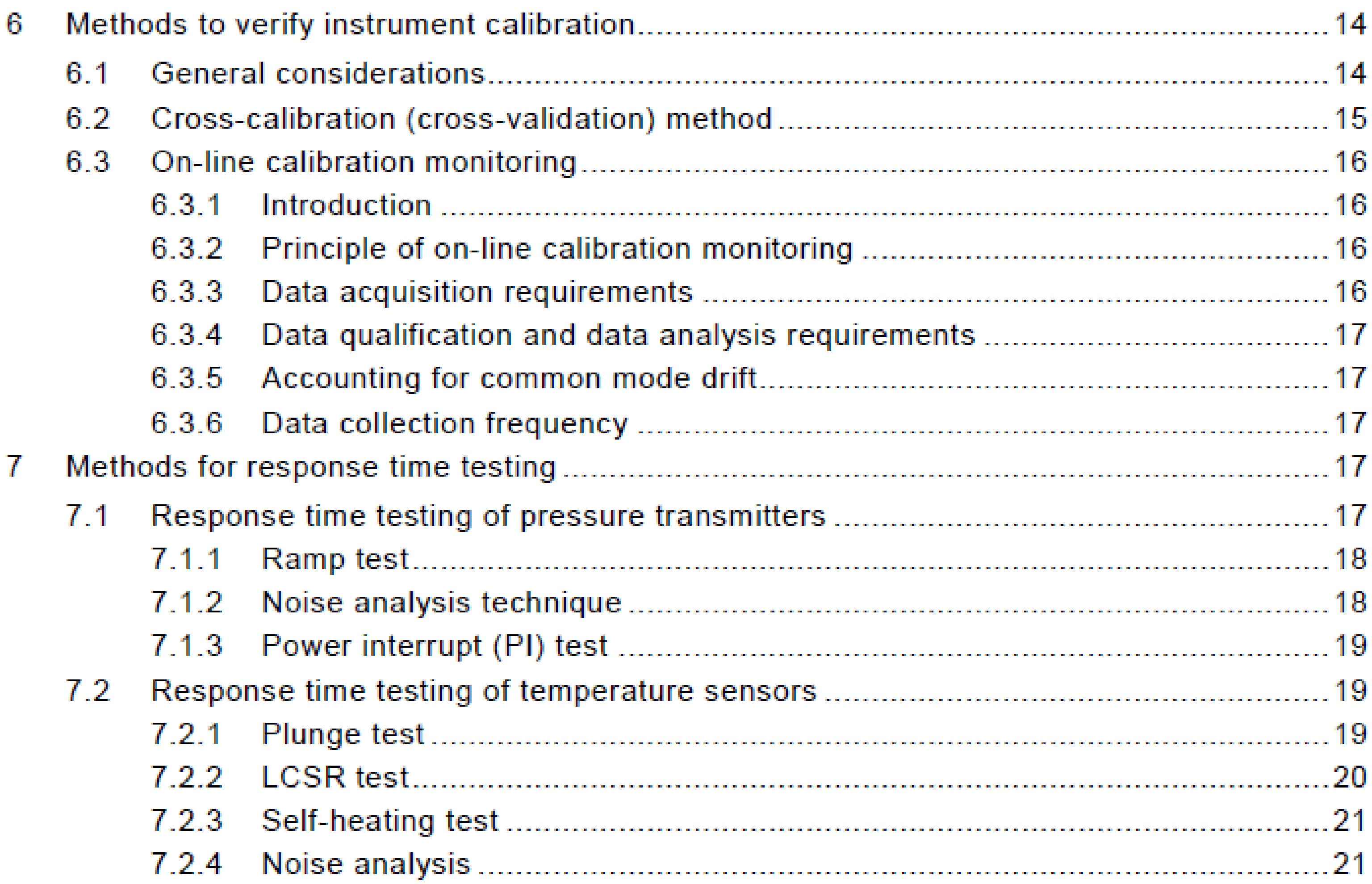
Condition Monitoring of Instruments

- Nuclear power plants employ a number of sensors to measure the process parameters for control of the plant and protection of its safety.
  - Taking pressure transmitter as an example
- IEC standards focus on online monitoring (OLM) techniques for sensors and transmitters performance assessment.
  - Nondestructive, in-situ and online as opposed to popular methods for cable condition monitoring.
  - Might be adapted for application in CBQ.
- Two major performance indicators
  - Static performance indicator
    - Calibration accuracy
  - Dynamic performance indicator
    - Response time
  - Both elaborated in IEC 62385

IEC 62385

- Standard title:
  - Nuclear power plants - Instrumentation and control important to safety - Methods for assessing the performance of safety system instrument channels
- Published on 2007-06-21
- Defines the requirements for demonstrating acceptable performance of safety system instrument channels through response time testing, calibration verification, and other means.
- The same requirements may be adopted for demonstrating the acceptable performance of non-safety systems and other instrument channels.

IEC 62385 for condition monitoring



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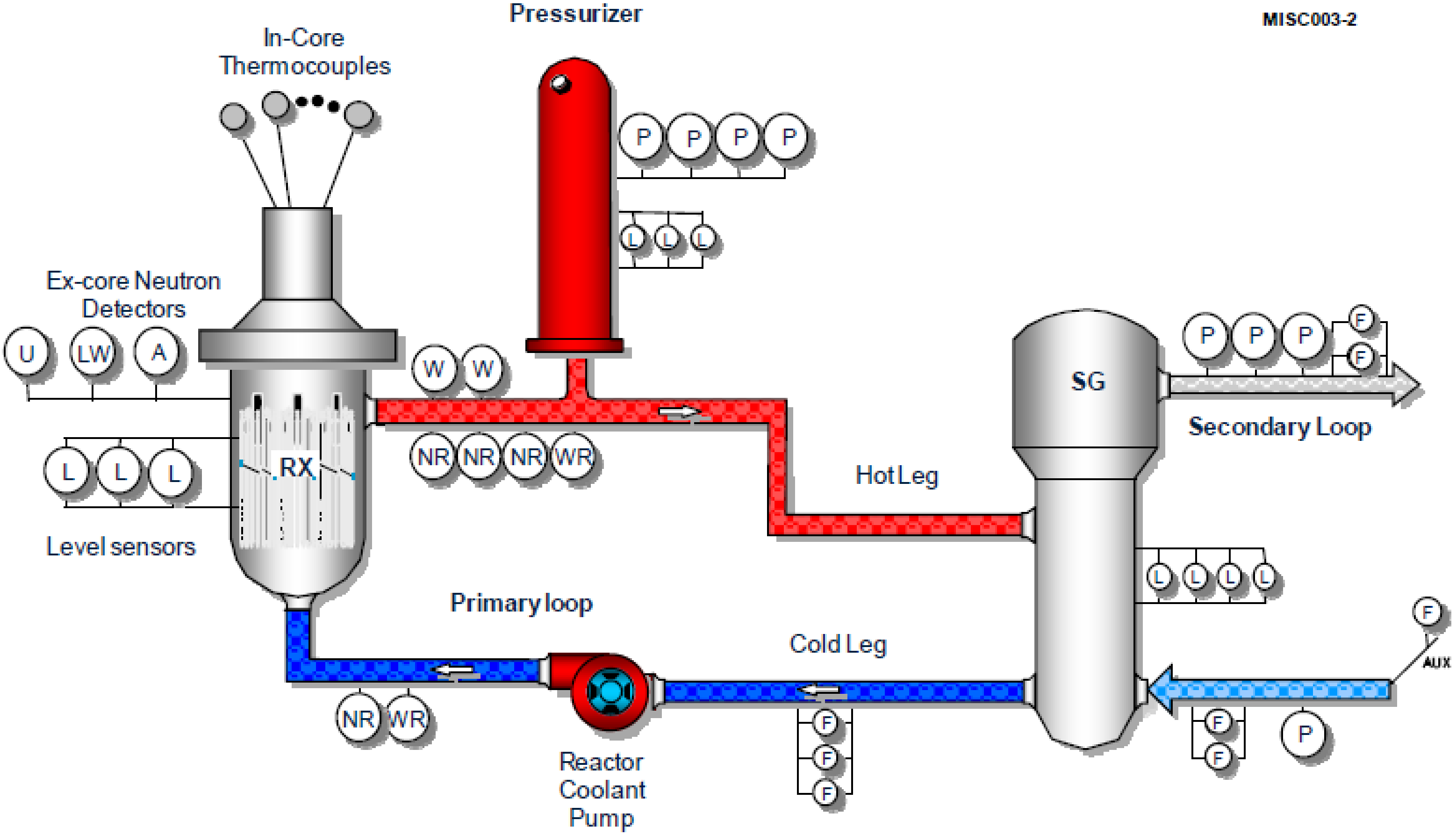
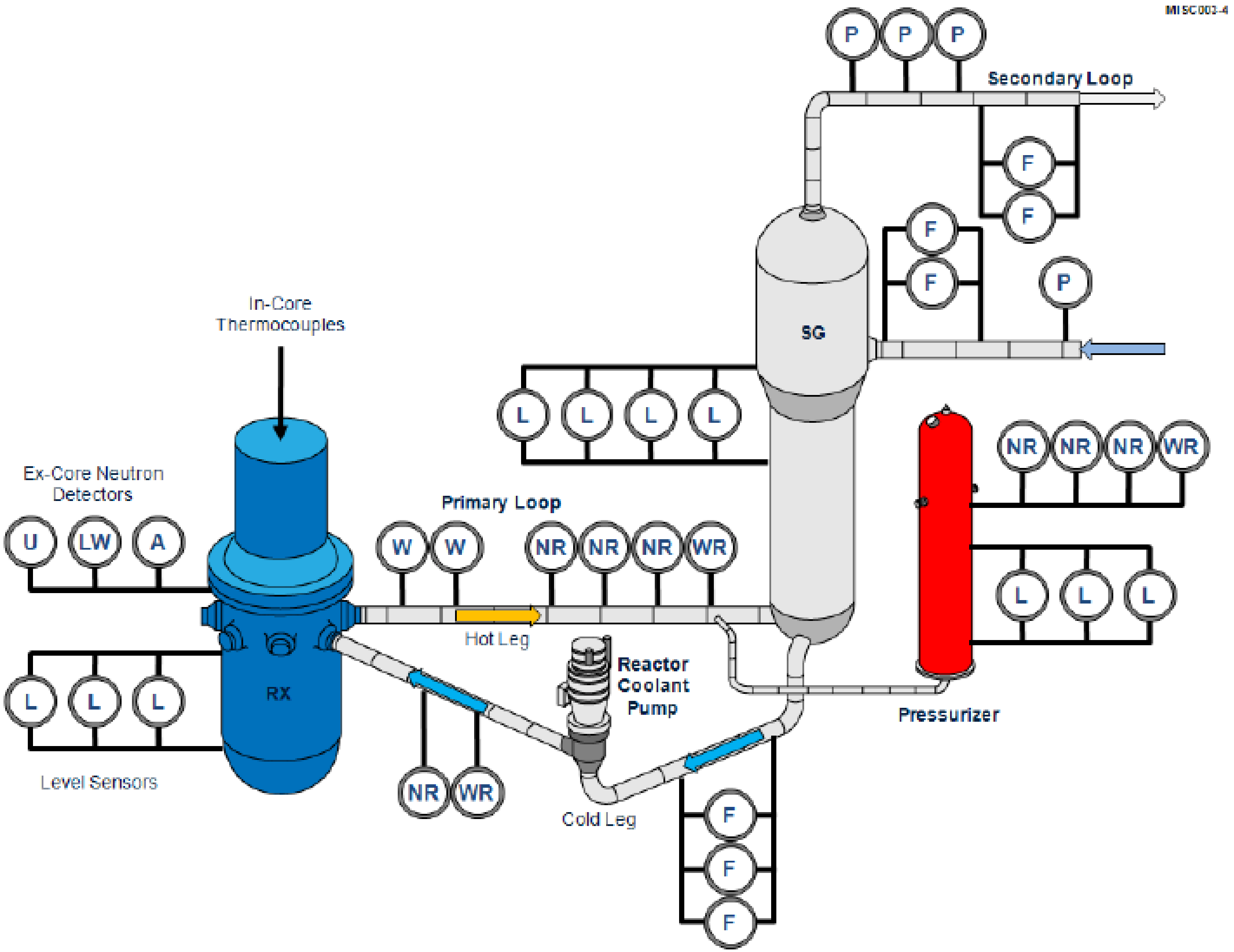


A:	Average Detector	RX:	Reactor
F:	Flow Transmitter	SG:	Steam Generator
L:	Level Transmitter	U:	Upper Detector
LW:	Lower Detector	W:	Wide-Range pressure
NR:	Narrow-Range RTDs	WR:	Wide-Range RTDs
P:	Pressure Transmitter		


MISC003-4
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Reactor
Coolant
Pump
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Pressurizer
Level Sensors
NR
WR
Cold Leg
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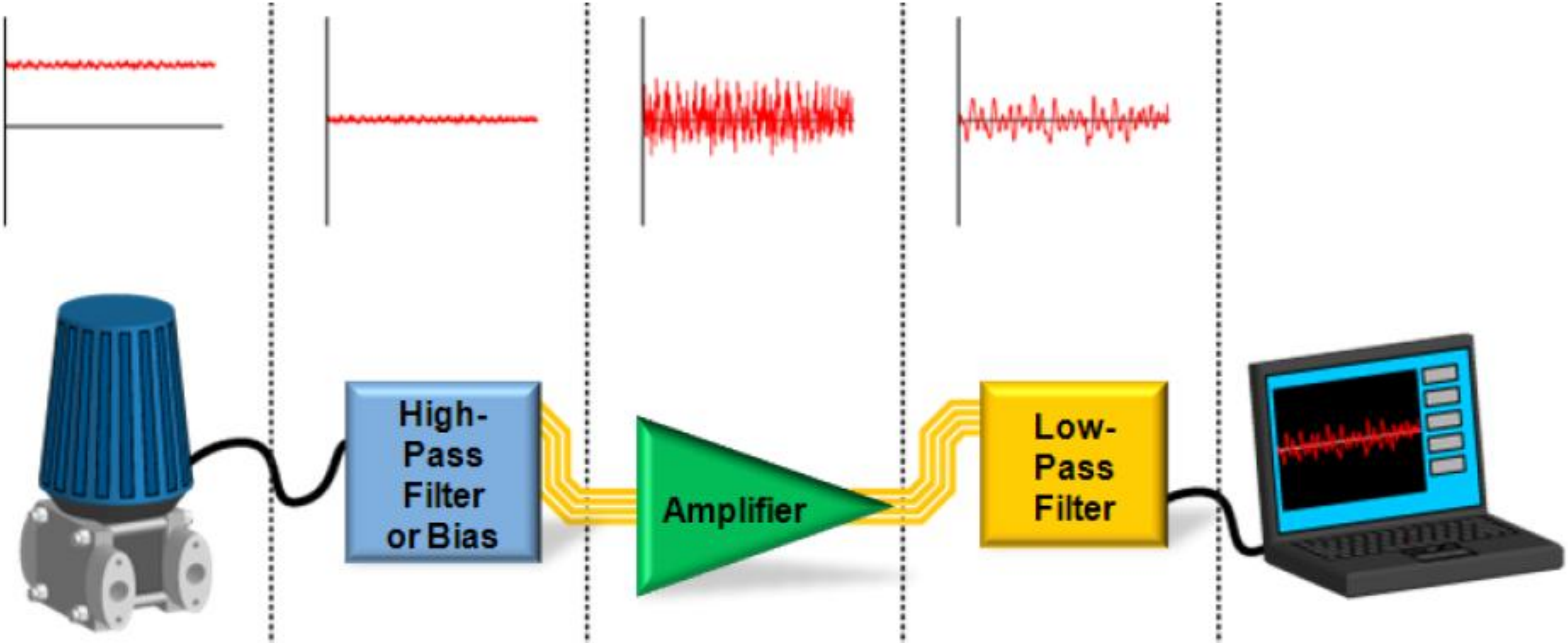
F

On-Line Calibration Monitoring of Pressure, Level, and Flow Transmitters

- Pressure, level, and flow transmitters in nuclear power plants are calibrated periodically to ensure reliable measurements and plant safety. These calibrations are typically performed once every fuel cycle; in most nuclear power plants, fuel cycles have a duration of about 18 to 24 months. Through calibration activities, substantial labor is devoted to isolating the instruments, calibrating them, and returning them to service. Reviews of calibration histories of process instruments in nuclear power plants have shown that high-quality instruments—such as nuclear-grade pressure transmitters—typically maintain their calibration for more than a fuel cycle of 18 to 24 months and do not, therefore, need to be calibrated as often.

On-Line Calibration Monitoring of Pressure, Level, and Flow Transmitters

- *On-line calibration monitoring refers to the monitoring of the normal output of pressure, level,* and flow instruments during plant operation and a comparison of the data with an estimate of the process parameter that the instrument is measuring. With this method, sensor outputs are monitored during process operation to identify drift.
- If drift is identified and is significant, the transmitter is scheduled for a calibration during an ensuing outage. On the other hand, if the transmitter drift is insignificant, no calibration is performed for as long as eight years, typically.



Isolated Plant Signal

Remove Static Component

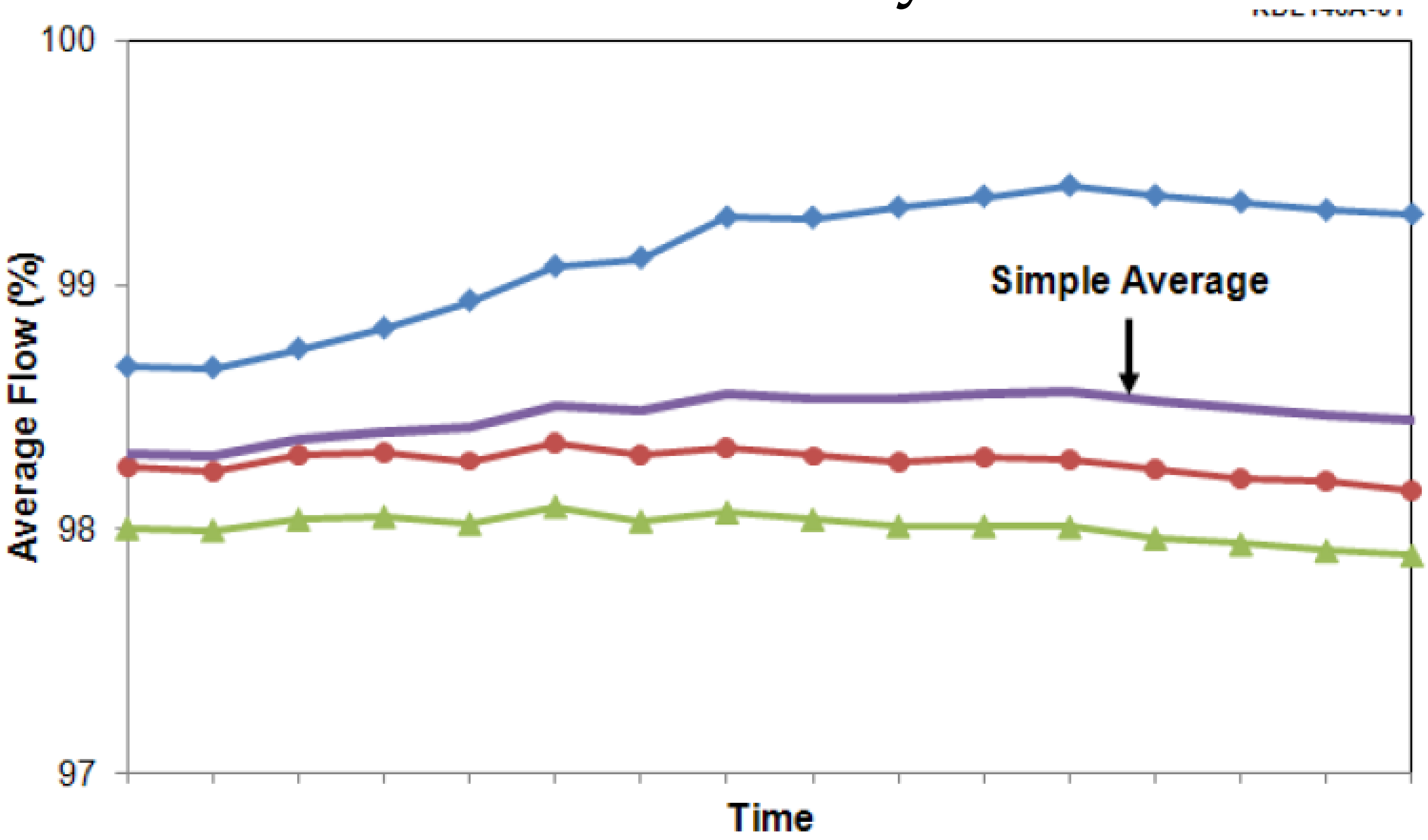
Amplify Dynamic Component

Filter for Anti-Aliasing and Removal of Extraneous Noise

Computer with A/D Converter

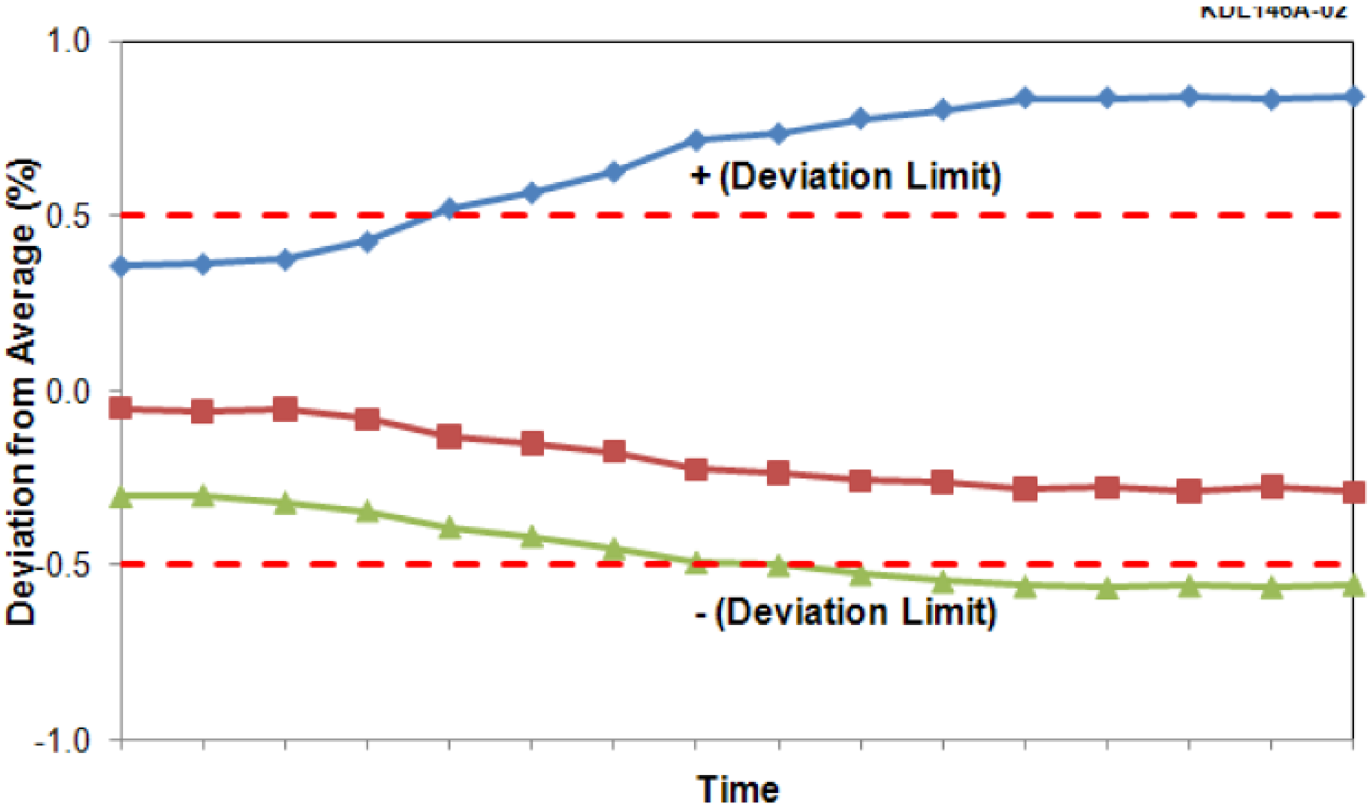
Deviation as a potential condition indicator

- Generated from static analysis methods



Deviation as a potential condition indicator

- Generated from static analysis methods



Dynamic Response of Pressure, Level, and Flow Transmitters

- Two methods have been developed and validated for in-situ response time testing of pressure transmitters as installed in operating processes.
  - These methods are referred to as the noise analysis technique and the power interrupt (PI) test.
- The noise analysis technique can be used for response time testing of most pressure transmitters, but the PI test is applicable only to force-balance pressure transmitters.
- Force-balance pressure transmitters are also testable by the noise analysis technique, but the PI test is more often used than the noise analysis technique, because the PI test involves a simpler procedure.

Dynamic Response of Pressure, Level, and Flow Transmitters

- More specifically, to perform the PI test, the power to the transmitter is turned off for a few seconds and then turned back on while the transmitter output is recorded. This test results in a transient output that is then analyzed to obtain the response time of the transmitter.
- The analysis involves stripping the exponential component of the data from the PI test transient and analyzing the exponential component to obtain the response time. The stripping of the exponential component is typically performed by a numerical technique and the analysis of the exponential component is typically performed by a least square fitting algorithm.

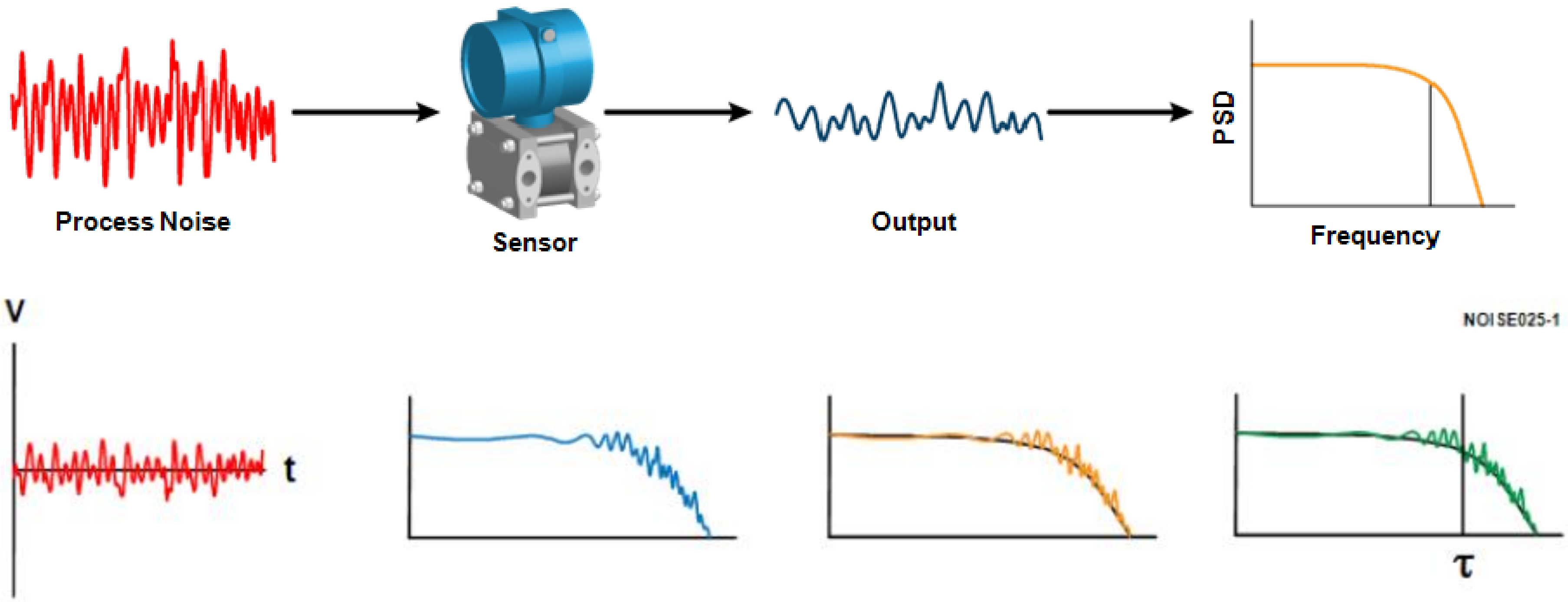
Dynamic Response of Pressure, Level, and Flow Transmitters

- Dynamic response analysis is performed in the frequency domain and/or time domain, and is based on the assumption that the dynamic characteristics of the transmitters are linear and the input noise signal (i.e., the process fluctuations) has proper spectral characteristics.
- Frequency domain and time domain analyses are two different methods for response time determination of transmitters and it is usually helpful to analyze the data with both methods and average the results excluding any outliers.

Dynamic Response of Pressure, Level, and Flow Transmitters

- In frequency domain analysis, the power spectral density (PSD) of the signal is first generated usually using a fast Fourier transform (FFT) algorithm.
- After the PSD is obtained, a mathematical function (model) that is appropriate for the transmitter under test is fit to the PSD to yield the model parameters that are then used to calculate the dynamic response of the transmitter.
- The dynamic response of the transmitter can then be analyzed to determine the transmitter's response time in-situ, without having to perform more time-consuming and invasive procedures such as ramp testing.
- Figure 2-8 shows examples of process noise that enters a pressure transmitter and is subsequently filtered by the transmitter. The response time of the transmitter can be inferred from the PSD with the proper analysis tools.

Frequency domain analysis

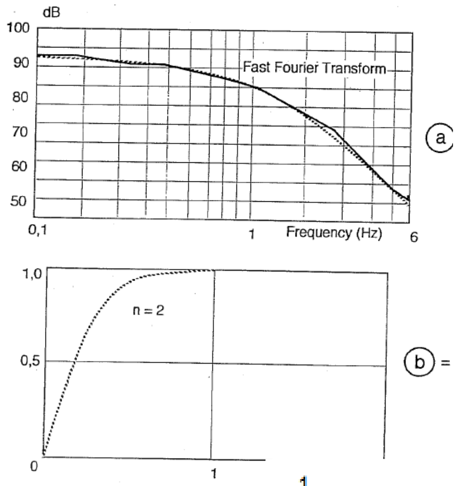


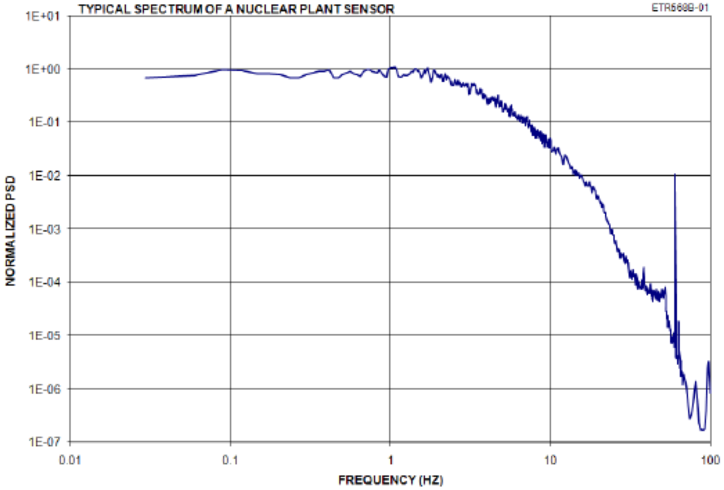
Data → PSD → Fit to PSD → Results

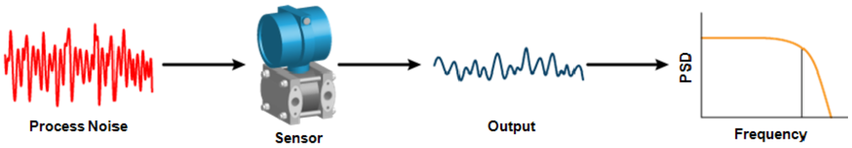
Frequency domain analysis

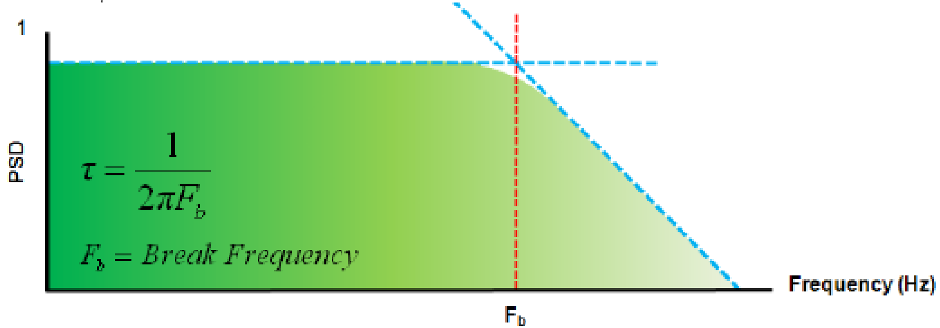
- Transfer function
  - IEC 61224 :Nuclear reactors - Response time in resistance temperature detectors (RTD) - In situ measurements

$$H_2(p) = \frac{\Pi_j(p - z_j)}{\Pi_i(p - p_i)}$$





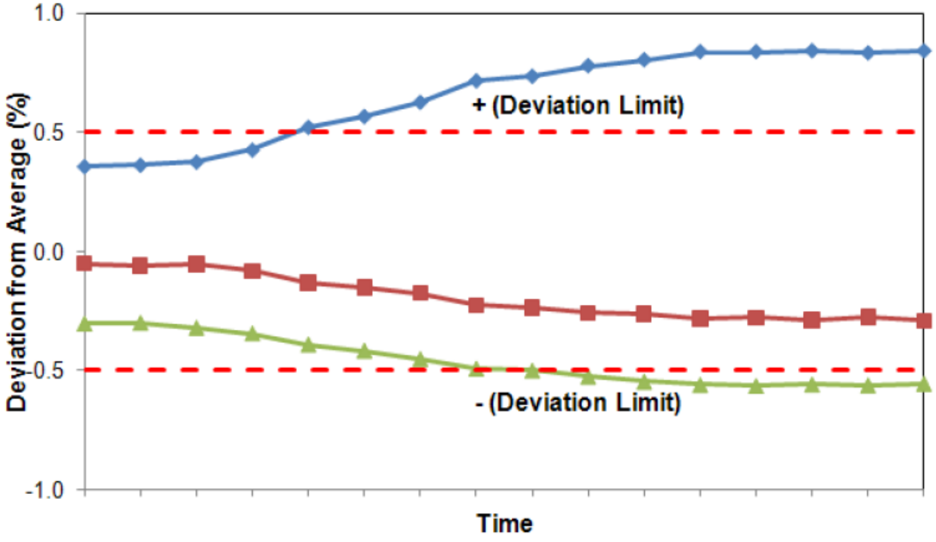


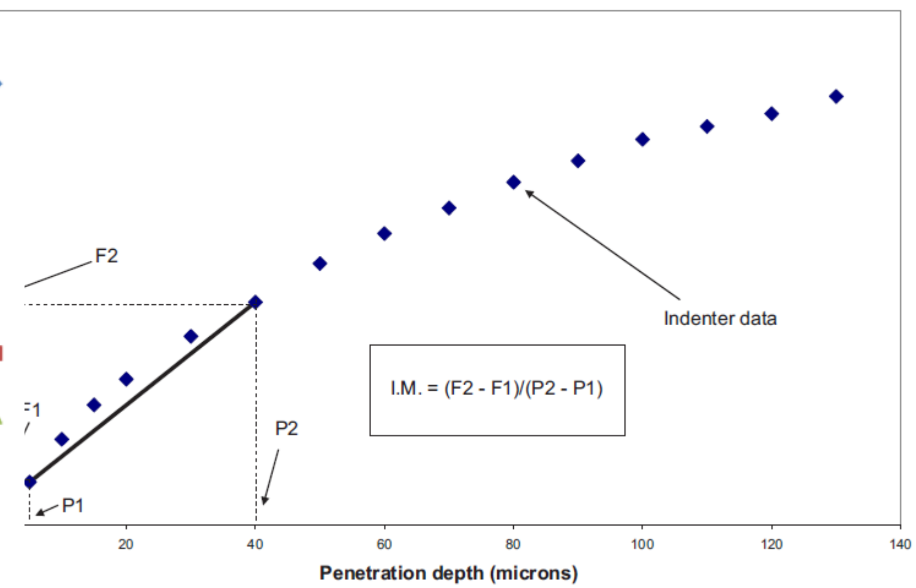


Comparison of CMs for cables and instruments

Comparison of condition monitoring methods for cables and transmitters

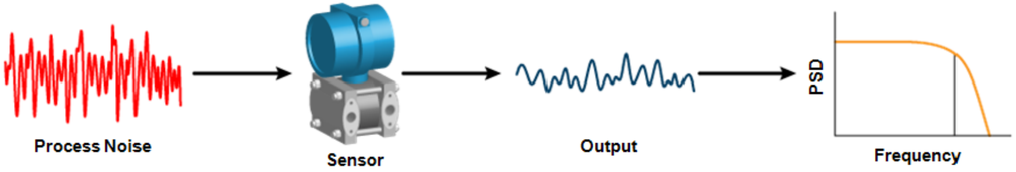
- Calibration drift vs. indenter modulus
  - Indentation is a non-destructive and mainly non-intrusive cable CM methods.
  - To carry out a measurement, the instrument must clamp around the cable jacket or insulation to be measured, and the probe only penetrates the surface of the test material a few hundred microns.

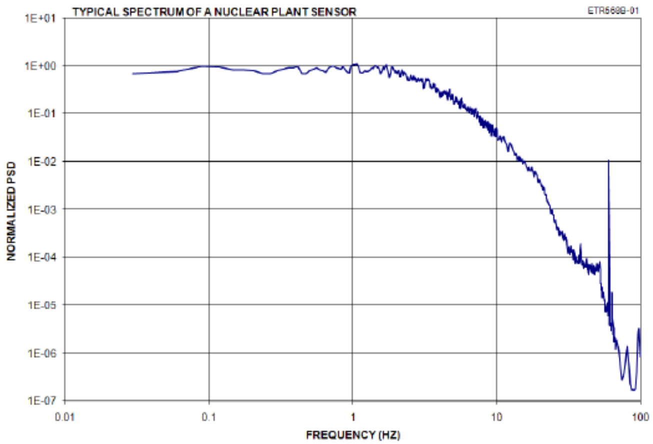


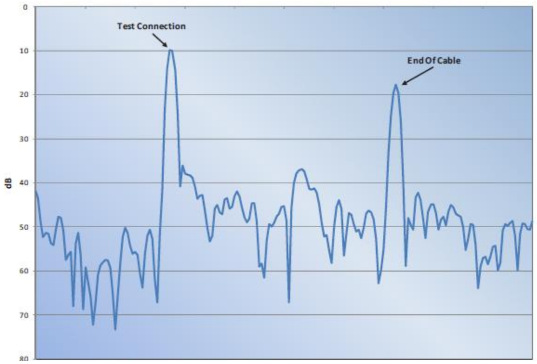


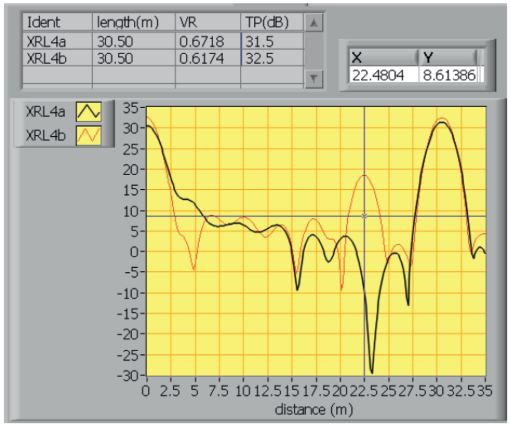
Comparison of condition monitoring methods for cables and transmitters

- Response time analysis vs. frequency domain reflectometry (FDR)
  - FDR is a non-destructive cable testing technique based on transmission line theory.
  - The behavior of a transmission line depends on its length in comparison with the wavelength of the electrical signal travelling into it.









Ident	length(m)	VR	TP(dB)
XRL4a	30.50	0.6718	31.5
XRL4b	30.50	0.6174	32.5

X	Y
22.4804	8.61386

FIG. 4.18. FDR measurement using LIRA on XLPE before (black line) and after (red line) local thermal ageing at 22.5 m.

Comparison of condition monitoring methods for cables and transmitters

- CBQ is not included in IEC EQ standard (60780) and thus it might make people think that seem that CM methods for instrumentation such as transmitters are not well developed.
- However, in-depth investigation reveal that a number of candidate CM methods are available in various IEC standards, which share many similarity with cable CM methods in the sense of static and dynamic parameters.
- These findings might reshape our vision about the prospect of CBQ for transmitters and sensors and other equipment.

Summary and Recommendation

Summary and Recommendation

- Condition based qualification has demonstrated its advantage over qualified-life based qualification approaches.
- The application of CBQ is primarily limited to the qualification and ageing management/ life extension of cable systems.
- CBQ is not integrated into the IEC qualification systems, but IEC has published a number of standards that directly or indirectly address condition monitoring methods for various purpose, including instrument performance assessment, I&C ageing management and cable condition monitoring.
- Those static and dynamic performance indictors developed in IEC standards resemble cable condition indicators, which qualify them as candidate condition indicators for implementing CBQ of sensors and transmitters.
- If successfully implemented, the application field of CBQ will be enormously expanded, which promises to further enhance plant safety for both new and old nuclear reactors.

Summary and Recommendation

- Though appealingly promising, it must be admitted that condition monitoring methods are limited to performance assessment of instrument channels to date.
- Few experiments or serious investigation have been conducted to justify and verify its validity for implementing CBQ.
- To better understand the nature of the opportunities and challenges, the industry is advised to,
  - Leverage experience and best practice from cable CBQ to expedite that process for instrumentation equipment.
  - Systematically summarize available CM methods with proven applicability.
  - Identify promising candidate CM methods and conduct tests or complementary analysis to justify them.
  - Gather lessons learned from these pilot activities and make continued efforts toward the objective of a well established system for qualifying instrumentations based on condition monitoring methods.

Work together and pave the road towards condition based qualification for nuclear power plant instruments.

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Better Natural Life

Thank you for your patience and attention.
Questions and comments are cordially welcome!