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# First-term Status Report for the Component Operational Experience Degradation and Ageing Programme (CODAP)

## 2011-2014

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Organisation de Coopération et de Développement Économiques
Organisation for Economic Co-operation and Development

**04-May-2015**

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**NUCLEAR ENERGY AGENCY**
**COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS**

# First-term Status Report on Component Operational Experience Degradation and Ageing Programme CODAP (2011-2014)

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## ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where the governments of 34 democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

The OECD member countries are: Australia, Austria, Belgium, Canada, Chile, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, the Republic of Korea, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission takes part in the work of the OECD.

OECD Publishing disseminates widely the results of the Organisation's statistics gathering and research on economic, social and environmental issues, as well as the conventions, guidelines and standards agreed by its members.

## NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1 February 1958. Current NEA membership consists of 31 countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, the Republic of Korea, the Russian Federation, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission also takes part in the work of the Agency.

The mission of the NEA is:

- to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes;
- to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information.

The NEA Data Bank provides nuclear data and computer program services for participating countries. In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

## THE COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

The NEA Committee on the Safety of Nuclear Installations (CSNI) is an international committee made up of senior scientists and engineers with broad responsibilities for safety technology and research programmes, as well as representatives from regulatory authorities. It was created in 1973 to develop and co-ordinate the activities of the NEA concerning the technical aspects of the design, construction and operation of nuclear installations insofar as they affect the safety of such installations.

The committee's purpose is to foster international co-operation in nuclear safety among NEA member countries. The main tasks of the CSNI are to exchange technical information and to promote collaboration between research, development, engineering and regulatory organisations; to review operating experience and the state of knowledge on selected topics of nuclear safety technology and safety assessment; to initiate and conduct programmes to overcome discrepancies, develop improvements and reach consensus on technical issues; and to promote the co-ordination of work that serves to maintain competence in nuclear safety matters, including the establishment of joint undertakings.

The priority of the committee is on the safety of nuclear installations and the design and construction of new reactors and installations. For advanced reactor designs, the committee provides a forum for improving safety-related knowledge and a vehicle for joint research.

In implementing its programme, the CSNI establishes co-operative mechanisms with the NEA's Committee on Nuclear Regulatory Activities (CNRA), which is responsible for the Agency's programme concerning the regulation, licensing and inspection of nuclear installations with regard to safety. It also co-operates with the other NEA Standing Technical Committees as well as with key international organisations such as the International Atomic Energy Agency (IAEA) on matters of common interest.

# EXECUTIVE SUMMARY

Structural integrity of piping systems is important for plant safety and operability. In recognition of this, information on degradation and failure of piping components and systems is collected and evaluated by regulatory agencies, international organisations (e.g., OECD/NEA and IAEA) and industry organisations worldwide to provide systematic feedback to reactor regulation and research and development programmes associated with non-destructive examination (NDE) technology, in-service inspection (ISI) programmes, leak-before-break evaluations, risk-informed ISI, and probabilistic safety assessment (PSA) applications involving passive component reliability.

Several OECD Member Countries have agreed to establish the OECD/NEA "Component Operational Experience, Degradation & Ageing Programme" (CODAP) to encourage multilateral co-operation in the collection and analysis of data relating to degradation and failure of metallic piping and non-piping metallic passive components in commercial nuclear power plants. The scope of the data collection includes service-induced wall thinning, part through-wall cracks, through-wall cracks with and without active leakage, and instances of significant degradation of metallic passive components, including piping pressure boundary integrity. The Project is organised under the OECD/NEA Committee on the Safety of Nuclear Installations (CSNI).

CODAP is the continuation of the 2002–2011 "OECD/NEA Pipe Failure Data Exchange Project" (OPDE) and the Stress Corrosion Cracking Working Group of the 2006–2010 “OECD/NEA SCC and Cable Ageing project” (SCAP). OPDE was formally launched in May 2002. Upon completion of the 3rd Term (May 2011), the OPDE project was officially closed to be succeeded by CODAP. SCAP was enabled by a voluntary contribution from Japan. It was formally launched in June 2006 and officially closed with an international workshop held in Tokyo in May 2010. Majority of the member organizations of the two projects were the same, often being represented by the same person. In May 2011, thirteen countries signed the CODAP 1st Term agreement (Canada, Chinese Taipei, Czech Republic, Finland, France, Germany, Korea (Republic of), Japan, Slovak Republic, Spain, Sweden, Switzerland and United States of America).

A key accomplishment of CODAP is the establishment of a framework for the systematic collection and evaluation of service-induced degradation and failure of passive metallic components. The Online Event Database facilitates data entry as well as database interrogation. The Online Knowledge Base allows for the capturing, sharing, transferring, storing and utilizing technical information on environmental degradation mechanisms, structural integrity evaluations, relevant R&D results, and national codes and standards for design and construction and in-service inspection.

The Online Event Database includes almost 4700 event records from 324 commercial nuclear power plants. The Online Knowledgebase includes country specific collections of documents and supporting information sorted by degradation mechanisms based on the events in the Online Event Database.

This project report describes the status of the First Term (2011-2014) of the CODAP event database and knowledge base. A review of the operating experience as documented in the event database addresses trends-and-patterns, the effectiveness of various strategies to mitigate environmental degradation, and the experience with non-destructive examination.

## TABLE OF CONTENTS

## LIST OF FIGURES

## LIST OF TABLES

## LIST OF ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| AFCN | Agence Fédérale de Contrôle Nucléaire |
| AMP | Ageing Management Program |
| ASME | American Society of Mechanical Engineers |
| ASN | L'Autorité de sûreté nucléaire |
| BMI | Bottom Mounted Instrument |
| CL | PWR Reactor Coolant System Cold Leg |
| CSNI | Committee on the Safety of Nuclear Installations |
| CSV | Character Separated Values |
| DEGB | Double-Ended Guillotine Break |
| DN | Nominal Diameter [mm] |
| E/C | Erosion-Corrosion |
| E-C | Erosion-Cavitation |
| EDF | Electricité de France |
| EMDA | Expanded Material Degradation Assessment |
| FAC | Flow Accelerated Corrosion |
| GALL | Generic Aging Lessons Learned |
| HL | PWR Reactor Coolant System Hot Leg |
| HT | Heat Transport |
| IAEA | International Atomic Energy Agency |
| IAGE | CSNI Working Group on Integrity and Ageing of Components and Structures |
| ID | Inside Diameter |
| IGALL | International Generic Aging Lessons Learned |
| ISI | In-Service Inspection |
| KB | Knowledge Base |
| LOCA | Loss-of-Coolant Accident |
| NEA | Nuclear Energy Agency |
| NDE | Non-Destructive Examination |
| OD | Outside Diameter |
| OECD | Organisation for Economic Co-Operation and Development- |
| OPDE | OECD Pipe Failure Data Exchange Project |
| PCSG | Pipe Cracking Study Group |
| PDA | Performance Demonstration Administrator |
| PDI | Performance Demonstration Initiative |
| PMDA | Proactive Materials Degradation Assessment |
| PRG | Project Review Group |
| PSA | Probabilistic Safety Assessment |
| RC | Reactor Coolant |
| RCPB | Reactor Coolant Pressure Boundary |
| RF | Refuelling Cycle |
| RHR | Residual Heat Removal |
| RI-ISI | Risk Informed In-Service Inspection |
| RIM | Reliability and Integrity Management |
| RT | Radiographic Testing |
| RV | Relief Valve |
| RPVIS | Reactor Pressure Vessel Internals |
| SCAP | Stress Corrosion Cracking and Cable Ageing Project |
| SW | Service Water |
| TRM | Technical Requirements Manual |
| UHS | Ultimate Heat Sink |
| UT | Ultrasonic Testing |
| VHP | Vessel Head Penetration |
| VT | Visual Inspection Technique |
| XML | Extensible Mark-up Language |

# 1. INTRODUCTION

Structural integrity of piping components and systems and non-piping passive components such as the reactor pressure vessel and internals is important for plant safety and operability. In recognition of this, information on degradation and failure of metallic piping and non-piping passive components is collected and evaluated by regulatory agencies, international organisations (e.g., OECD/NEA and IAEA) and industry organisations worldwide to provide systematic feedback for example to reactor regulation and research and development programmes associated with ageing phenomena, non-destructive examination (NDE) technology, in-service inspection (ISI) programmes, leak-before-break evaluations, risk-informed ISI, and probabilistic safety assessment (PSA) applications involving passive component reliability.

Since 2002, the OECD/NEA has operated an event database project that collects information on passive metallic component degradation and failures of the primary system, reactor pressure vessel internals, main process and standby safety systems, and support systems (i.e., ASME Code Class 1, 2 and 3, or equivalent), as well as non-safety-related (non-code) components with significant operational impact. With an initial focus on piping systems and components (the OPDE Project), the scope of the project in 2011 was expanded to also address the rector pressure vessel and internals as well as certain other metallic passive components that are susceptible to environmental degradation. In recognition of the expanded scope, the Project Review Group approved the transition of OPDE to a new, expanded "Component Operational Experience, Degradation & Ageing Programme" (CODAP).

## 1.1 Project History

Reviews of service experience with safety-related and non-safety-related piping systems have been ongoing ever since the first commercial nuclear power plants came on line in the 1960's. In 1975 the U.S. Nuclear Regulatory Commission established a Pipe Crack Study Group (PCSG) charged with the task of evaluating the significance of stress corrosion cracking in boiling water reactors (BWRs) [1] and pressurised water reactors (PWRs) [2]. Service experience review was a key aspect of the work by the PCSG. Major condensate and feedwater piping failures (e.g., Trojan and Surry-2 in the U.S.) due to flow accelerated corrosion (FAC) resulted in similar national and international initiatives to learn from service experience and to develop mitigation strategies to prevent recurrence of pipe failures [3][4][5]. Early indications of the significance of thermal fatigue phenomena evolved in the 1970s, and, again, systematic reviews of the service experience enabled the introduction of improved piping design solutions, NDE methods, and operating practices [6].

The team of analysts responsible for the seminal Reactor Safety Study (WASH-1400) [7] performed a limited evaluation of nuclear and non-nuclear power plant piping reliability based on field experience data on pipe failures. This evaluation was aimed at estimation of loss-of-coolant-accident (LOCA) frequencies for input to the two PSA models of WASH-1400. After the publication of WASH-1400 in 1975 many other R&D projects have explored the roles of structural reliability models and statistical evaluation models in providing acceptable input to PSA. Furthermore, during the past 20 years efforts have been directed towards establishment of comprehensive pipe failure event databases as a foundation for exploratory research to better understand the capabilities and limitations of today's piping reliability analysis frameworks. Risk-informed piping reliability analysis relies on statistical evaluations of validated operating experience data, complemented with structural reliability modeling insights.

Assessment of passive component service experience data has been an integral element of regulatory and industry programs to address long term operation and nuclear plant license renewal. Examples of such programs include the Proactive Materials Degradation Assessment (PMDA), Expanded Materials Degradation Assessment (EMDA), Generic Aging Lessons Learned (GALL) and International Generic Aging Lessons Learned (IGALL).[1] A common feature of these four programs is the acknowledgement of systematic reviews of the accumulated service experience data as one-of-several inputs to the development of a technical basis for practical ageing management of metallic passive components.

In parallel with these focused efforts to evaluate service experience data and to correlate the occurrence of material degradation with piping design and operational parameters, initiatives have been presented to establish an international forum for the systematic collection and exchange of service experience data on piping. An obstacle to the use of the database by other countries of national qualitative and quantitative pipe failure information is that criteria and interpretations applied in the collection and analysis of events and data differ among the various countries. A further impediment is that the descriptions of reported events and their root causes and underlying contributing factors, which are important to the assessment of the events, are usually written in the native language of the countries where the events were observed.

To overcome these obstacles, the preparation for the OECD Pipe Failure Data Exchange (OPDE) Project was initiated in 1994 by the Swedish Nuclear Power Inspectorate (SKI)[2]. In 1994 SKI launched a 5-year R&D project to explore the viability of creating an international pipe failure database. During this period SKI hosted meetings to present results of the R&D and to discuss the principles of database development and maintenance.[3] Since May 2002, the OECD/NEA has formally operated the project under the coordination of the Committee on the Safety of Nuclear Installations (CSNI). The first term of the Project covered the years 2002-2005, the second term covered the period 2005-2008, and the final term covered the period 2008-2011 [8].

In May 2011 the Project Review Group (PRG) approved the transition of OPDE to a new, expanded OECD-NEA Component Operational Experience, Degradation & Ageing Programme (CODAP). A first CODAP National Coordinators Meeting was held at NEA Headquarters in November 2011. The CODAP PRG Membership corresponds to that of the OPDE, with two additional member countries (Slovak Republic and Chinese Taipei). The CODAP project builds on the success of OPDE and a related OECD-NEA data project, the SCAP-SCC Working Group.

In 2006 the SCC and Cable Ageing Project (SCAP) was established under the auspices of the OECD/NEA to assess, due to their implication on nuclear safety and their relevance for plant ageing management, two subjects: stress corrosion cracking (SCC) and degradation of cable insulation. The project ran successfully from June 2006 to June 2010 [9]. SCAP was financed through a Japanese voluntary contribution to the NEA.

Fourteen NEA member countries joined the SCAP project in 2006 to share knowledge and by 2010 seventeen countries had joined the project. The International Atomic Energy Agency (IAEA) and the European Commission, through its Joint Research Centre in Petten, also participated as observers.

The objective of the SCAP coordinated project was to share the corporate knowledge and operating experience, to understand the failure mechanisms, and to identify effective techniques and technologies to

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[1] Detailed information on PMDA, EMDA and GALL are available at www.nrc.gov. The IGALL is summarized in IAEA-TECDOC-1736 (April 2014), which is available at www.iaea.org.

[2] Swedish Radiation Safety Authority (SSM) as of July 1, 2008

[3] In September 1996 SKI organised the “Initial Meeting of the International Cooperative Group on Piping Performance” with participants from thirteen countries. Again, in September 1997 SKI organized the “Seminar on Piping Reliability” (SKI Report 97:32); this time with participants from eleven countries.

effectively manage and mitigate active degradation in nuclear power plants. The specific objectives of the project were to:

- Establish a complete database with regard to major ageing phenomena for SCC and degradation of cable insulation through collective efforts by OECD/NEA members.
- Establish a knowledge base in these areas by compiling and evaluating the collected data and information systematically.
- Perform an assessment of the data and identify the basis for commendable practices which will help regulators and operators to enhance ageing management.

The scope of the SCAP SCC Working Group activities covered class 1 and 2 pressure boundary components, reactor pressure vessel internals and other components with significant operational impact, excluding steam generator tubing. The entire SCC database consisted of an event database and general information. The general information consisted of regulations/codes & standards, inspection/monitoring/qualification, preventative maintenance/mitigation, repair/replacement, safety assessment, and R&D. Together these information categories comprised the Knowledge Base.

## 1.2 Transition from OPDE to CODAP

Following the completion of the SCAP project, SCC Working Group participants were interested in some form of continuation and discussions were initiated to explore possible alternatives. It was recognised that there were many aspects very similar to those existing in OPDE and the concept of a new project was envisaged to combine the two projects into the “Component Operational Experience, Degradation & Ageing Programme” (CODAP). The objective of CODAP is to collect information on passive metallic component degradation and failures of the primary system, reactor pressure vessel internals, main process and standby safety systems, and support systems (i.e., ASME Code Class 1, 2 and 3, or equivalent). It also covers non safety-related (non-Code) components with significant operational impact.

During the three OPDE Project Terms (2002-2011), the event database was maintained and distributed as a Microsoft® Access database. This database was distributed on a CD to the National Coordinators twice per calendar year. Towards the end of the first Project Term, a web-based database format was developed to facilitate data exchange. The web-based OPDE resided on a secure server at the NEA Headquarters. With the 2011 transition from OPDE to CODAP, a new and enhanced web-based database format was implemented. As of mid-2012, the entire CODAP event database resides on a secure server at NEA Headquarters. Provisions exist for online database interrogation (e.g., event review, QA, queries) as well as downloading queries (in CSV- or XML-file format) and selected event records or entire database (in XML-file format) to a local computer or computer network. In addition to the event database, CODAP includes a web-based Knowledge Base (KB) that contains relevant national and international reference material on passive metallic component damage and degradation mechanisms. Included in the KB are codes and standards, R&D results, regulatory frameworks, and country-specific aging management programs. As for the event database, the KB resides on a secure server at NEA Headquarters.

## 1.3 Report Structure

Section 2 describes the CODAP objective and scope. The CODAP organization and quality assurance program are described in Sections 3 and 4, respectively. The event database and knowledge base are described in Section 5 and 6, respectively. A selective and high-level review of the operating experience with piping and non-piping passive components is documented in Section 7. It addresses trends-and-patterns, the effectiveness of various strategies to mitigate environmental degradation, and the experience with non-destructive examination. Database accessibility is addressed in Section 8. Conclusions and future plans are addressed in Section 9. Finally, a list of references is included in Section 10. Appendix A includes a CODAP-PRG activity report, and Appendix B is a glossary of terms.

# 2. CODAP OBJECTIVE AND SCOPE

CODAP is the continuation of the 2002-2011 “OECD/NEA Pipe Failure Data Exchange Project” (OPDE) and the work by the Stress Corrosion Cracking Working Group of the 2006 – 2010 “OECD/NEA SCC and Cable Ageing Project” (SCAP). OPDE was formally launched in May 2002. Upon completion of the 3rd Term in May 2011 the OPDE project was officially closed. SCAP was enabled by a voluntary contribution from Japan. It was formally launched in June 2006 and officially closed with an international workshop held in Tokyo in May 2010. Most of the members of the two projects were the same, often being represented by the same person. The scope of the CODAP is based on a combination of the concepts from the two projects. Thus it encompasses service experience data on metallic piping and non-piping passive components and well as a Knowledge base as in SCAP but addressing the full range of failure mechanisms as in OPDE.

## 2.1 Data Collection Methodology

The CODAP Project exchanges data on passive component degradation and failure, including service-induced wall thinning, non-through wall crack, leaking through-wall crack, pinhole leak, leak, rupture and severance (pipe break caused by external impact). For non-through wall cracks the CODAP scope encompasses degradation exceeding design code allowable for wall thickness or crack depth as well as such degradation that could have generic implications regarding the reliability of in-service inspection (ISI) techniques. The following failure modes are considered[4]:

- Non-through wall defects (e.g., cracks, wall thinning) interpreted as structurally significant and/or exceeding design code allowable;
- Loss of fracture toughness of cast austenitic stainless steel piping. The loss of fracture toughness is attributed to thermal ageing embrittlement.
- Through-wall defects without active leakage (leakage may be detected following a plant operational mode change involving depressurization and cool-down, or as part of preparations for non-destructive examination, NDE);
- Small leaks (e.g., pinhole leak, drop leakage) resulting in piping repair or replacement;
- Leaks (e.g., leak rates within Technical Specification limits);
- Large leaks (e.g., flow rates in excess of Technical Specification limits);
- Major structural failure (pressure boundary "breach" or "rupture").

In other words, the CODAP Event Database collects data on the full range of degraded conditions, from "precursors" to major structural failures. The structural integrity of a pressure boundary is determined

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[4] Appendix E of the CODAP “Coding Guideline” documents the different national reporting thresholds.

by multiple and interrelated reliability attributes and influence factors. Depending on the conjoint requirements for damage and degradation, certain combinations of material, operating environment, loading conditions together with applicable design codes and standard, certain passive components are substantially more resistant to damage and degradation than others. As an example, for stabilized austenitic stainless steel pressure boundary components, there are no recorded events involving active, through-wall leakage. By contrast, for unstabilized austenitic stainless steel, multiple events involving through-wall leakage have been recorded, albeit with relative minor leak rates. Flow-accelerated corrosion (FAC), if unmonitored, is a relatively aggressive degradation mechanism that has produced major structural failures, including double-ended guillotine breaks (DEGB). The types of pipe failure included in the CODAP Event Database are:

- Event-based failures that are attributed to damage mechanisms and local pipe stresses. Examples include high-cycle vibration fatigue due to failed pipe support, and hydraulic transient (e.g., steam or water hammer) acting on a weld flaw (e.g., slag inclusion).

- Failures caused by environmental degradation such as stress corrosion cracking due to combined effects of material properties, operating environment (e.g., corrosion potential, irradiation) and loading conditions.

The CODAP Event Database is a web based, relational database consisting of ca. 100 uniquely defined data fields. It is a blend of free-format fields for detailed narrative information and fields defined by drop-down menus with key words (or data filters) or related tables. A basic premise of the use of narrative information is to preserve original event information as recorded in root cause evaluation reports and reportable occurrence reports. The "related tables" include information on material, location of damage or degradation, type of damage or degradation, system name, safety class, etc. The event database structure, database field definitions and data input requirements are defined in a coding guideline, which is central to the project, including database maintenance, data validation and quality control. The database design has benefitted from a multidisciplinary approach involving chemistry, metallurgy, non-destructive examination, structural integrity and PSA. Each event record relates to a uniquely defined component boundary.

### 2.2 CODAP Knowledge Base

The CODAP Knowledge Base (KB) has been established to systematically compile basic international technical information of relevance to the project. The KB is password protected and resides on a secure server at NEA Headquarters in Paris, France. The KB is intended to provide a source of information on technical issues related to all the failure mechanisms covered by the Event Database. The type of information collected includes regulations, codes and standards with respect to inspection/monitoring/ non-destructive examination qualification, preventive maintenance/mitigation, repair/replacement, operability determination, safety assessment/risk characterization, and R&D. The information is both of a general nature and also more specific for the different degradation mechanisms. The KB is intended to provide a source of systematically organised information for the project members, as well as input to the topical reports that are prepared by the PRG members. There is a search function to facilitate retrieval of information.

The KB is a web-based area of the CODAP project domain. It is organised as a hierarchical system of folders for general information, degradation specific information and a country folder for each project member. The country folders have two purposes: 1) to upload files for inclusion in the common KB, and 2) to provide a means of organising documents of national interest and relevance. In the latter case documentation can be in the language of the country, with a title in English. In the other folders all documents are in English.

# 3. PROJECT ORGANISATION

This section describes the CODAP project organization. The Operating Procedures, a controlled document, describes the project organization, infrastructure and additional guidelines for the project to achieve the objectives as stated in the CODAP Terms and Conditions for project operation.

## 3.1 Responsibilities of Project Participants

All power for the CODAP resides with the signatory countries bound by a legal agreement “Terms & Conditions.” The Project Review Group (PRG), formed by the representatives of the signatories (normally the National Coordinator) and an OECD/NEA representative holds all the power to make decisions on running the project. Signatories may involve other bodies in their countries by separate operational agreements.

## 3.2 The NEA Secretariat

OECD/NEA is responsible for administering the project according to OECD rules. This means secretarial and administrative services in connection with the funding of the Project such as calling for contributions, paying expenses incurred in connection with the Operating Agent and Knowledge Base (KB) Coordinator, and keeping the financial accounts of the Project. NEA appoints the Project Secretariat.

## 3.3 CSNI

The OECD/NEA Committee for Safety of Nuclear Installations (CSNI) acts as an umbrella committee of CODAP. Prior to publication of project-related results, all public domain reports prepared by the CODAP Project Review Group undergo independent review by the CSNI.

The CSNI is an international committee made up of senior scientists and engineers, with broad responsibilities for safety technology and research programmes, and representatives from regulatory authorities. It was set up in 1973 to develop and co-ordinate the activities of the NEA concerning the technical aspects of the design, construction and operation of nuclear installations insofar as they affect the safety of such installations.

The committee’s purpose is to foster international co-operation in nuclear safety amongst the OECD member countries. The main tasks of the CSNI are to exchange technical information and to promote collaboration between research, development, engineering and regulatory organisations; to review operating experience and the state of knowledge on selected topics of nuclear safety technology and safety assessment; to initiate and conduct programmes to overcome discrepancies, develop improvements and research consensus on technical issues; to promote the coordination of work that serves to maintain competence in the nuclear safety matters, including the establishment of joint undertakings. While the primary focus of the committee is on existing power reactors and other nuclear installations; it also considers the safety implications of scientific and technical developments of new reactor designs.

The CSNI Working Group on Integrity and Ageing of Components and Structures (IAGE) has as general mandate to advance the current understanding of those aspects relevant to ensuring the integrity of structures, systems and components, to provide for guidance in choosing the optimal ways of dealing with challenges related to the integrity of operating, as well as new nuclear power plants, and to practice an integrated approach to design, safety and plant life management. In this context, CODAP is improving the quality of data obtained relating to piping and non-piping passive component degradation experience, and, in turn, rendering such data more useful in predicting structural component degradation and failure.

### 3.4 CODAP Project Review Group

The CODAP Project Review Group (PRG) runs the Project, with assistance from the NEA Project Secretary, the Operating Agent and KB Coordinator. The PRG meets at least once per year. The PRG responsibilities include but are not limited to the following types of decisions:

- Secure the financial and technical resources necessary to carry out the Project
- Nominate the CODAP project chairperson
- Define the information flow (public information and confidential information)
- Approve the admittance of new members
- Nominate project task leaders (lead countries) and key persons for the PRG tasks
- Define the priority of the task activities
- Monitor the progress of the project and task activities
- Approve and monitor the work of the Operating Agent and quality assurance
- Approve and monitor the work of the Knowledge Base Coordinator.

### 3.5 The Operating Agent

To assure consistency of the event database data contributed by the National Coordinators the Project operates through an Operating Agent. The Operating Agent verifies whether the event information provided by the National Coordinators complies with the CODAP Coding Guidelines (CG); CODAP-PR01 [10]. It also verifies the completeness and accuracy of the data and assigns the quality index jointly with respective National Coordinator who has provided such data.

The CODAP Applications Handbook (CODAP-AH) [11] includes guidelines for extracting insights from the event database about material degradation, including failure trends and event population data for input to statistical parameter estimation tasks. It includes descriptions of the data processing steps that are needed to facilitate statistical evaluations of operating experience with metallic piping components and non-piping passive components. Whereas the CODAP Coding Guideline (CODAP-CG) defines database structure and data submission requirements, the CODAP-AH includes guidelines for creating database queries and associated data processing steps. CODAP-AH is a companion document to CODAP-CG.

## 3.6 The Knowledge Base Coordinator

To assure consistency of the KB material and information contributed by the National Coordinators the Project operates through a KB Coordinator. The KB Coordinator verifies whether the material and information provided by the National Coordinators complies with the KB Structure; CODAP-PR04.

# 4. QUALITY ASSURANCE PROGRAM

The objective of the Quality Assurance Programme (QAP) is to establish organizational and technical principles and measures for quality assurance (QA) and monitoring of the work during operation of the CODAP Project to ensure high quality of the final product (CODAP Event Database, CODAP Knowledge Base, and companion reports). The QAP applies to all activities in the project and is to be followed by all project participants.

## 4.1 Principles of Data Quality

To achieve the objectives established for the CODAP event database a coding format has been developed. This Coding Format is reflected in the Coding Guideline. The Coding Guideline builds on established pipe failure data analysis practices and routines that acknowledge the unique aspects of passive component reliability in heavy water reactor and light water reactor operating environments (e.g., influences by material and water chemistry).

For an event to be considered for inclusion in the event database it must undergo an initial screening for eligibility.[5] An objective of this initial screening is to go beyond the abstracts of event reports to ensure that only pipe degradation and failures according to the work scope definition are included in the database.

Data quality is affected from the moment the field experience data is recorded at a nuclear power plant, interpreted, and finally entered into a database system. The field experience data is recorded in different types of information systems ranging from action requests, work order systems, via ISI databases and outage summary reports, to licensee event reports or reportable occurrence reports. Consequently the details of a degradation event or failure tend to be documented to various levels of technical detail in these different information systems. Building a CODAP event database record containing the full event history often entails extracting information from multiple sources.

The term “data quality” is an attribute of the processes that have been implemented to ensure that any given database record (including all of its constituent elements, or database fields) can be traced to the source information. The term also encompasses “fitness-for-use”, that is, the database records should contain sufficient technical detail to support database applications.

In CODAP, a “Completeness Index” (CI) is used for database management purposes. It distinguishes between records for which more information must be sought and those considered to be complete (Table 1). Each record in the database is assigned a CI, which relates to the completeness and comprehensiveness of the information in the database relative to the requirements of the Coding Guideline.

The “Completeness Index” is also intended as a database filter for determination of the ‘fitness-for-application.’ The range of possible database applications covers advanced applications (e.g., the study of the effect of different water chemistries on specific degradation susceptibilities), risk-informed applications (e.g., technical basis for degradation mechanism assessment in risk-informed ISI programme development, or statistical parameter estimation in support of internal flooding PSA), and high-level

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[5] Section 5 covers database scope.

summaries of service experience trends and patterns. Advanced database applications would normally rely on queries that are address specific subsets of the overall database content. By contrast, high-level database applications would draw on information from the entire database content.

**Table 1: CODAP Completeness Index (CI) Definitions**

| Completeness Index | Description |
|---|---|
| 1 | Validated – all source data have been reviewed – no further action is expected |
| 2 | Validated – source data may be missing some non-essential information – no further action anticipated. The term "non-essential" implies that information about piping layout (including location of a flaw) may not be known exactly but can be inferred based on other, similar events (at same or similar plant) |
| 3 | Not validated – validation pending |

Completeness also relates to the completeness of the event population in the database. The Operating Agent periodically monitors the completeness of CODAP by comparing how other data sources capture noteworthy events.

## 4.2 QAP Scope

The QA Programme covers all aspects of the CODAP Project, including:

- Confidentiality (see below for additional details);
- Coding Guidelines (see below for additional information);
- Event Database development and maintenance. Any updating of database structure or content, including database scope issues, can be performed only by the Operating Agent with technical support from NEA-IT and must first be approved by the PRG;
- Knowledge Base development and maintenance. Any updating of KB structure or content can be performed only by the KB Coordinator with technical support from NEA-IT and must first be approved by the PRG;
- Data collection and data exchange. Data collection and coding of national data is performed by National Coordinators or persons/organizations to whom/which the NC delegates this responsibility. The data submitted to Operating Agent should be approved by the national authorities/utilities and ready for data exchange.;
- Data submittal. The National Coordinators are responsible for data submissions;
- Distribution of information. Official distribution of project documentation takes place via publication on the password protected Project website;
- External review. In certain cases the CODAP PRG may submit a document containing general information for review by the CSNI or a CSNI Working Group (e.g., the "Integrity of Components and Structures", or "Operating Experience"). After completion of a review and subsequent comment approval by the CODAP PRG, a document containing general information is published as a CSNI report.

## 4.3 Confidentiality

The CODAP Project differentiates between public domain information and confidential information. There are three levels of confidential information:

1. Level 1. Applies to all documentation developed by the Project Review Group. It is published on the password protected Project website. Selected Level 1 documents may become available to interested parties via external reporting by OECD/NEA. Such documents must undergo review and approval by the CSNI.

2. Level 2. Applies to the Online CODAP event database, national data and data analysis results. This material is kept on the NEA Secure Server, is password protected, and can be accessed only by authorized users. It is distributed only among active PRG members under the Terms & Conditions, is never published on the Project Web Site or distributed outside of the PRG.

3. Level 3. Applies to proprietary raw data and associated reference material used in creating database records. This material is kept on the NEA Secure Server. PRG members who are interested in this material shall contact the appropriate National Coordinator. In the web-based event database, any attachment containing proprietary information is clearly marked as a "Level 3" document.

## 4.4 Coding Guideline

To achieve the objectives of the CODAP Project, a Coding Format is developed. This Coding Format is reflected in the Coding Guideline (CODAP-PR01) which is a controlled document. The Coding Guideline builds on established passive component failure data analysis practices and routines that acknowledge the unique aspect of passive component reliability (e.g., influence by material and water chemistry). All database development and data coding activities are to be based on the Coding Guideline.

# 5. CODAP EVENT DATABASE

The CODAP Event Database is a web based, relational database consisting of ca. 100 uniquely defined data fields. It is a mixture of free-format fields for detailed narrative information, fields defined by drop-down menus with key words (or data filters) or related tables, and hyperlinks to additional background information (e.g., photographs, root cause evaluation reports). The "related tables" include information on material, location of damage or degradation, type of damage or degradation, system name, safety class, etc. At the end of the First Term the CODAP Event Database included ca. 4,700 records on degraded and failed metallic piping and non-piping passive components. Section 5 presents the scope of the event database and summarizes the database structure and main features of the Online Event Database.

## 5.1 Scope of Event Database

The event database scope and structure, database field definitions and data input requirements are defined in the Coding Guideline, which is central to the project, including database maintenance, data validation and quality control. The database design has benefitted from a multidisciplinary approach involving chemistry, metallurgy, structural integrity and PSA expertise.

The CODAP Event Database collects service experience data on the full range of degraded conditions, from "precursors" to major structural failures involving metallic piping components and non-piping metallic passive components. According to the IAEA Safety Glossary [12], a passive component is defined in the following way:

- A passive component is “component whose functioning does not depend on an external input such as actuation, mechanical movement or supply of power.
    - A passive component has no moving part, and, for example, only experiences a change in pressure, in temperature or in fluid flow in performing its functions. In addition, certain components that function with very high reliability based on irreversible action or change may be assigned to this category.
    - Examples of passive components are heat exchangers, pipes, vessels, electrical cables and structures. It is emphasized that this definition is necessarily general in nature, as is the corresponding definition of active component.
    - Certain components, such as rupture discs, check valves, safety valves, injectors and some solid state electronic devices, have characteristics which require special consideration before designation as an active or passive component.”

With the above definition as a basis and building on the OPDE and SCAP-SCC project experience, recent operating experience and associated regulatory actions, the Project Review Group made further refinements and specializations to arrive at a scope definition as summarized in Table 2. Consistent with the Operating Procedures, the scope definition is revisited and periodically updated. In Table 2, the column “Metallic, Non-Piping Passive Components” captures the BWR and PWR internals as documented and evaluated in IAEA-TECDOC-1471 [13] and IAEA-TECDOC-1119 [14], respectively.

**Table 2: Scope of CODAP Event Database**

| | Metallic Piping Components | Metallic, Non-Piping Passive Components |
|---|---|---|
| **Passive Component Category** | Safety-related piping | Reactor pressure vessel (RPV) |
| | Non-safety related piping | RPV internals |
| | Fire water system piping | Heat Exchanger (H/X) |
| | Small-, medium- and large-diameter piping | Steam Generator (S/G) |
| | Above-ground piping | Pump casing |
| | Below-ground (buried) piping | Pressurizer |
| | Pressure Tubes - PHWR | Valve body |
| | | Bolting |
| | | Calandria Vessel - PHWR |
| | | Tank |
| **Passive Component Types** | Bend | BMI - Bottom Mounted Instrument Nozzle (PWR) |
| | Bend – Long Radius | Bracket / Console |
| | Bend – Short Radius | Canopy Weld |
| | Branch connection | Collector assembly (WWER) |
| | Branch connection - butt welded | Control Rod Guide Tube Support Pin |
| | Branch connection - socket welded | Core Plate |
| | Elbow | Core Shroud |
| | Elbow – 90-Degree | Core Shroud Head Bolt |
| | Elbow – 45-Degree | Core Shroud Weld |
| | Flange | Core Spray Sparger (BWR) |
| | Expander | Core Spray Sparger Weld (BWR) |
| | Expansion joint | Core Support |
| | Flange | CRDM Housing |
| | Mixing tee | CRDM Nozzle |
| | Pipe | CST - Condensate Storage Tank |
| | Pipe - BONNA | Diffuser Plate |
| | Pipe - buried / below ground | Heater Sleeve (Pressurizer) |
| | Pipe - cement lined | H/X Shell |
| | Pipe - epoxy / PVC lined | ICI Tube |
| | Pipe - rubber lined | In-Core Instrument Guide Tube Nozzle |
| | Reducer | In-Core Monitoring Housing |
| | Reducing elbow | J-Groove Weld |
| | Reducing tee | Jet Pump Hold-Down Beam (BWR) |
| | Tee | Jet Pump Riser (BWR) |
| | Weld – butt | Lower Fuel Element Alignment Pin |
| | Weld – socket | PHB Diaphragm Plate |
| | | RPV Head |
| | | RPV Bottom Head |
| | | RWST - Refueling Water Storage Tank |
| | | S/G Partition Plate |
| | | S/G Shell |
| | | S/G Tube (restricted to tubing of Alloy 690 or Alloy 800 material) |
| | | SBLC Tank (BWR) |
| | | Steam Dryer |
| | | Upper Fuel Element Alignment Pin |
| | | VHP - RPV Vessel Head Penetration |

In CODAP the term “failure” covers the full spectrum of degraded conditions, from rejectable flaws requiring repair or replacement to major structural failures. As an example, ASME Section XI, Article IWA-3000 [15] defines acceptance standards for flaws that are discovered during non-destructive examinations (NDEs). Flaws determined to be rejectable (i.e., not fit for continued operation) according to relevant NDE code are required to be repaired or replaced.

## 5.2 Working with the Event Database

CODAP is a relational database. The data entry is managed via input forms, tables, roll down menus and database relationships. Figure 1 shows the Online opening screen and Figure 2 shows the Online main work area. The Online Version is accessible via a secure server at the Nuclear Energy Agency Headquarters. User names and passwords are provided by NEA IT-Department upon written request by National Coordinator. The Online Version includes help menus. The project members’ work area includes a FAQ area as wells as tutorials on how to input data and perform searches and queries.

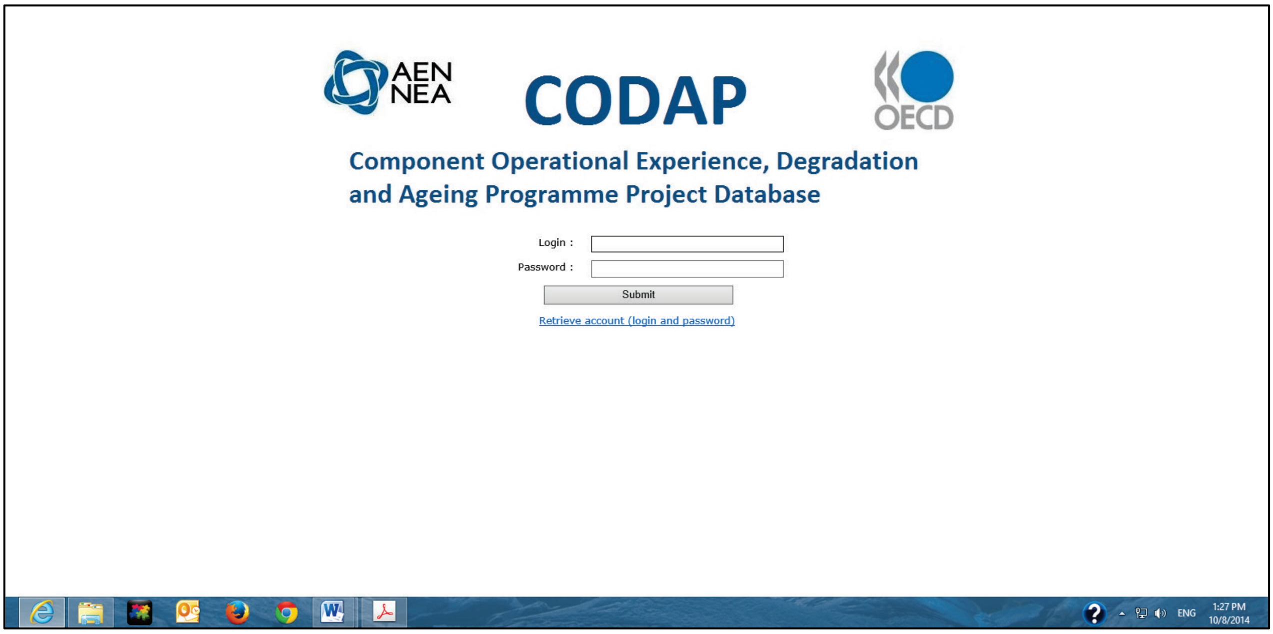

**Figure 1: CODAP Database Opening Screen**

The Main Menu page is displayed in Figure 2. There are a total of seven (7) sub-meus: 1) Records, 2) Create, 3) Search, 4) Statistics, 5) Delete, 6) Export, and 7) Help. The online user-interface supports the full suite of database operations, from initial data submission and QA through applications:

- **Records**. This menu provides an overview of th entire database content and provides basic information such as plant name, event date, when records was first created, when a record was last updated as well as QA status (i.e., draft, validation pending, validation completed. This menu supports database mangement.

- **Create**. The data input format is equivalent to that presented in Section 5. Each record added to the database is assigned a unique “EID/Key” number”. “Create new record” opens the data input form. A partially filled in form can be saved and retrieved and the information modified as needed. Use the “Tab Key” to move from form one field to another. The user may append attachments (e.g., drawings, photographs, PDF files) to a data record.

- **Search**. This tab includes two areas: 1) Search Criteria, and 2) Result Column. The entire database can be searched and filtered by a very large number of attributes.

- **Statistics**. This tab supports basic database queries. The query results can be exported to a local computer as a CSV (Character-Separated Value) file or XML (Extensible Markup Language) file. Selecting "CSV" automatically generates an Excel-file with the tabular query results. Additional post-processing of data may be performed on a local computer/computer network.

- **Delete**. This tab enables deletion of individual records or a set of records. Only NEA-IT and the Operating Agent can execute this function and upon pre-approval by respective National Coordinator.

- **Export**. Downloading records from the Online Version is straightforward. Pressing the "Export" button returns a listing of all records. Selected records or the entire database can be exported to a local computer. The Online Version creates a zip-file ("Export" file") that can be opened or saved to a local disc. The data records are converted to a XML file format that is compatible with Microsoft® Office programs (e.g., Access, Excel, Word).

- **Help**. This tab provides user support. It includes abbreviated versions of the Coding Guidelines and Applications Handbook.

For technical assistance, please contact CODAP webmaster or Mr. Bengt LYDELL

Figure 2: CODAP Main Menu

### 5.3 High-Level Database Summary[6]

The CODAP event database content is summarized in Tables 3 and 4 and Figures 3 through 5. Operating experience insights are covered in Section 7. Table 3 summarizes database content by Project Member Country. In Table 4 the database content is summarized by plant type (BWR, PHWR, or PWR), failure mode and passive component category, that is, piping versus non-piping passive component. The latter category includes Reactor Pressure Vessel Internals (RPVIS). The CODAP “Terms and Conditions”

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[6] This summary of the database content is current as of 30-November-2014

and "Operating Procedures" define the expectations regarding data submissions. Respective National Coordinator has overall responsibility for data submissions.

Figure 3 is a graphical representation of the database content by geographical region (European Union, incl. Switzerland, and Pacific Basin Region[7]). Included in this chart is the number of operating reactor units that produced the operating experience. Figure 4 shows the cumulative number of failure records over the time period covered by CODAP (1970 to 2014). Figure 5 is a summary of damage & degradation mechanisms. A more detailed presentation of the passive component operating experience insights is documented in Section 7.

**Table 3: Database Content by Participating Country**

| Project Members | | Number of Data Submissions |
|---|---|---|
| Country | Status | |
| BE | Member of OPDE Term 1 & 2 (2002-2008) | 8 |
| CA | Member since 2002 | 187 |
| CH | Member since 2002 | 95 |
| CZ | Member since 2002 | 25 |
| DE | Member since 2002 | 350 |
| ES | Member since 2002 | 50 |
| FI | Member since 2002 | 56 |
| FR | Member since 2002 | 148 |
| JP | Member since 2002 | 287 |
| KR | Member since 2002 | 69 |
| MX | Member of SCAP-SCC Project (2006-2010) | 3 |
| SE | Member since 2002 | 365 |
| SK | Member since 2011 | 5 |
| TW | Member since 2011 | 15 |
| US | Member since 2002 | 3035 |
| CODAP Event Database Content - No. of Records: | | 4698 |

**Table 4: Database Content by Plant Type & Passive Component Category**

| Plant Type | OPDE (2002-2011)[8] | | CODAP (2011-2014) | | | |
|---|---|---|---|---|---|---|
| | Piping | | Piping | | Non-Piping incl. RPVIS | |
| | Part Through-Wall | Through-Wall | Part Through-Wall | Through-Wall | Part Through-Wall | Through-Wall |
| BWR | 816 | 946 | 1033 | 984 | 85 | 37 |
| PHWR | 55 | 99 | 67 | 111 | 5 | 10 |
| PWR | 296 | 1581 | 340 | 1660 | 184 | 182 |
| Totals: | 1167 | 2626 | 1440 | 2755 | 274 | 229 |

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[7] With respect to CODAP, the Pacific Basin Region includes the following project member countries: Canada, Chinese-Taipei, Japan, Korea (Republic of), and USA.

[8] The OPDE database was based on an in-kind contribution by the Swedish regulatory authority. This in-kind contribution consisted of an Access database on pipe failure events in commercial nuclear power plants (1970-1998). The event population consisted of 2290 event records.

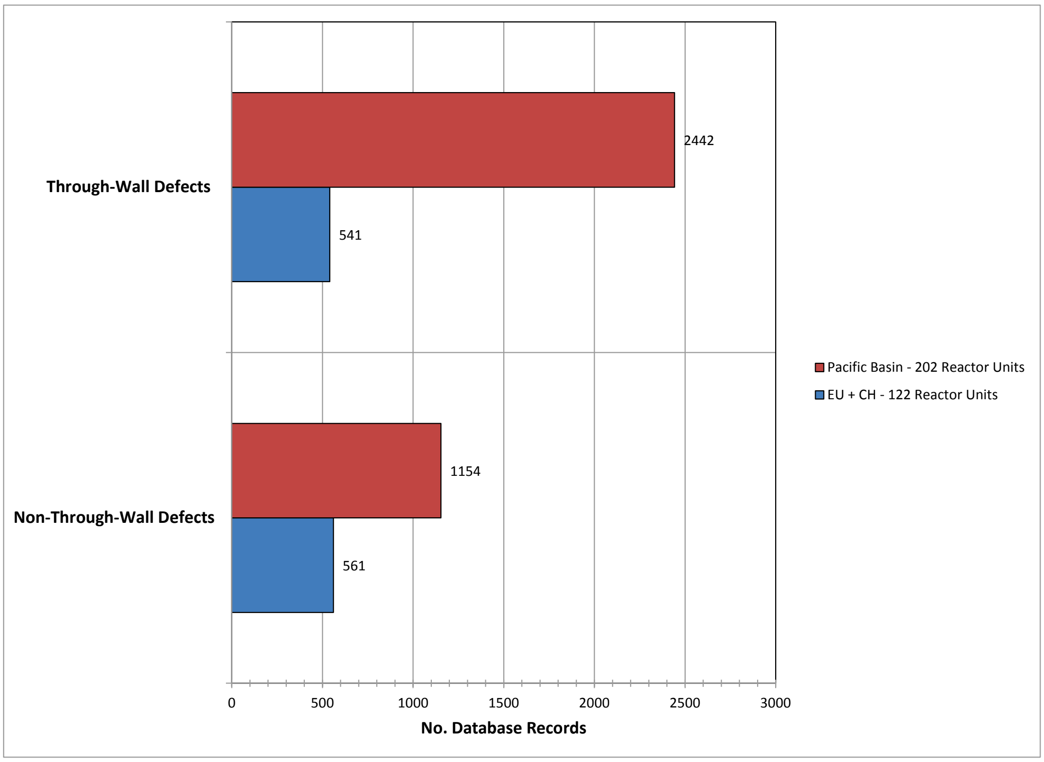


Figure 3: Database Content by Geographic Region

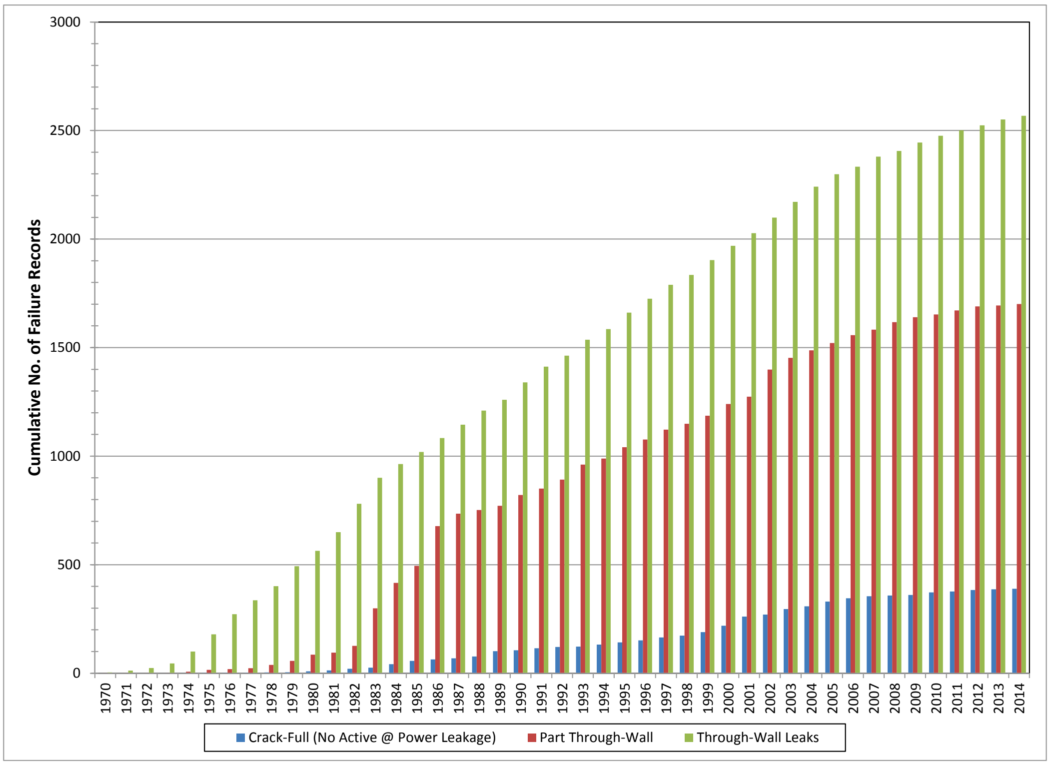


Figure 4: Cumulative Number of Failure Records

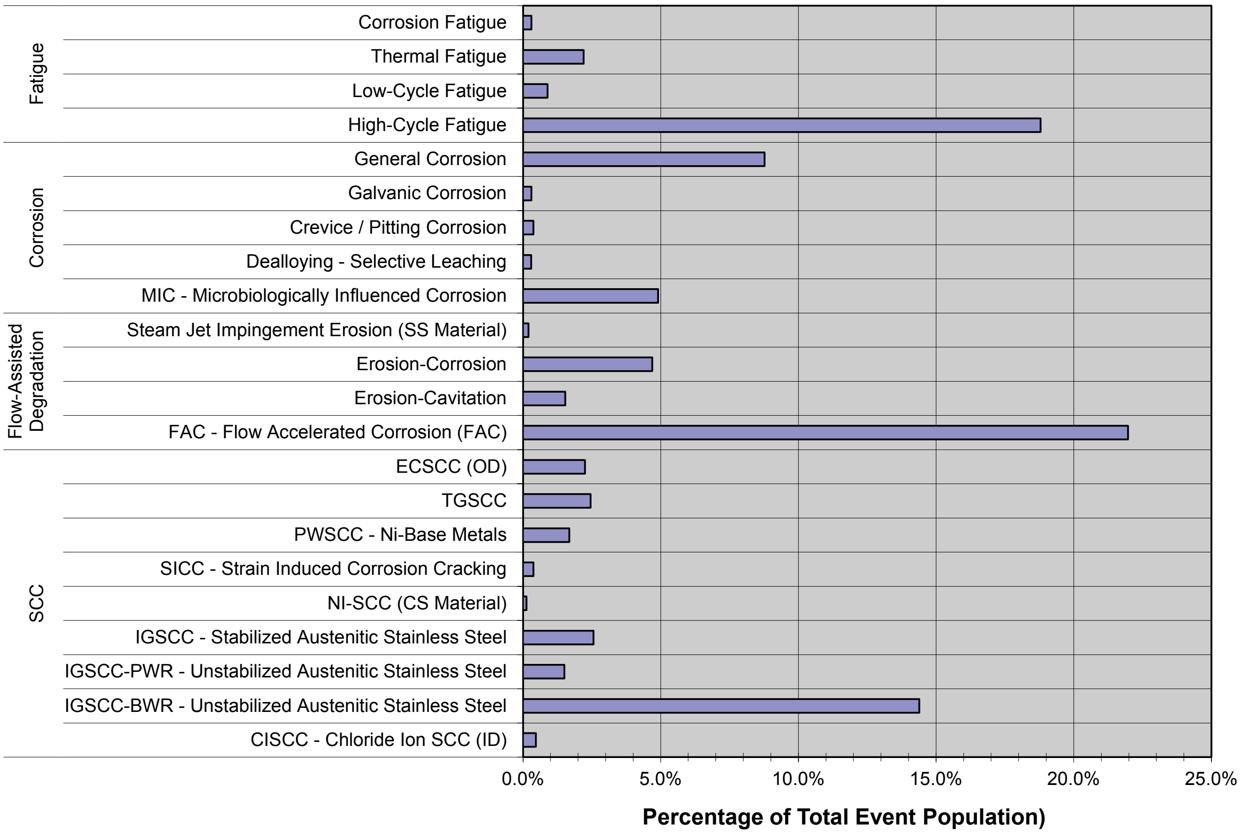


Figure 5: Damage / Degradation Mechanisms in CODAP Event Database

# 6. CODAP KNOWLEDGE BASE

The CODAP Knowledge Base (KB) has been established to reflect basic international technical information of relevance to the project in a systematic manner. The KB is password protected and resides on a secure server at NEA Headquarters in Paris, France. The KB is intended to provide a source of information on technical issues related to all the failure mechanisms covered by the Event Database. The type of information collected includes regulations/codes and standards, inspection/ monitoring/qualification, preventive maintenance/mitigation, repair/replacement, safety assessment, and R&D. The information is both of a general nature and also more specific for the different damage and degradation mechanisms. The KB is intended to provide a source of systematically organized information for members, as well as input to the topical reports that the project is preparing. There is a search function to facilitate retrieval of information.

## 6.1 Knowledge Management

In principle, the objective of knowledge management (KM) involves preserving institutional or corporate knowledge about a specific subject matter [16]. In the context of CODAP, KM involves preserving the discipline-specific analysis methods and techniques, phenomenology associated with environmental degradation mechanisms, research and development, operating experience, codes-and-standards, design and construction, safety analysis, licensing, flaw tolerance evaluations, long term operation, and aging management. In CODAP the approach to KM is through implementation of a web-based Knowledge Base. The CODAP KB builds on the experience gained from the SCAP-SCC Project, which undertook to develop a KB on stress corrosion cracking [9].

## 6.2 Structure of CODAP-KB

The CODAP Knowledge Base consists of a collection of documents and supporting information arranged in a manner such that it is easily retrievable by participants. Documentation is in English (or the original language together with an English translation). The information is sorted according to the different degradation mechanisms in the Event Database.

The structure of the Knowledge Base is hierarchical such that generic information which is applicable to all, or many, of the degradation mechanisms lies highest and then the specific degradation mechanisms lie below. This information is common and accessible to all participants. The information at each level will comprise, but not be limited to:

- Regulations, Codes and Standards;
- Inspection, monitoring, qualification;
- Damage and degradation mechanism information;
- References, e.g., technical reports, archival journal articles, conference proceedings;
- Important events (Reference events from the Event database) will be included in the mechanism specific areas.

Participating countries can collect national information in their country folders. Material in country folders need not be translated except for the title. This ensures that the Knowledge Base Coordinator can assess the relevance of material for inclusion in the common area.

The content of the Knowledge Base is defined and agreed by the PRG together with the Knowledge Base Coordinator and the Operating Agent. The structure of the KB is illustrated in Figure 6 and the web-based KB Work Area is illustrated in Figure 7. The web-based KB includes an advanced search capability (Figure 8), and an example of a KB search results is illustrated in Figure 9.

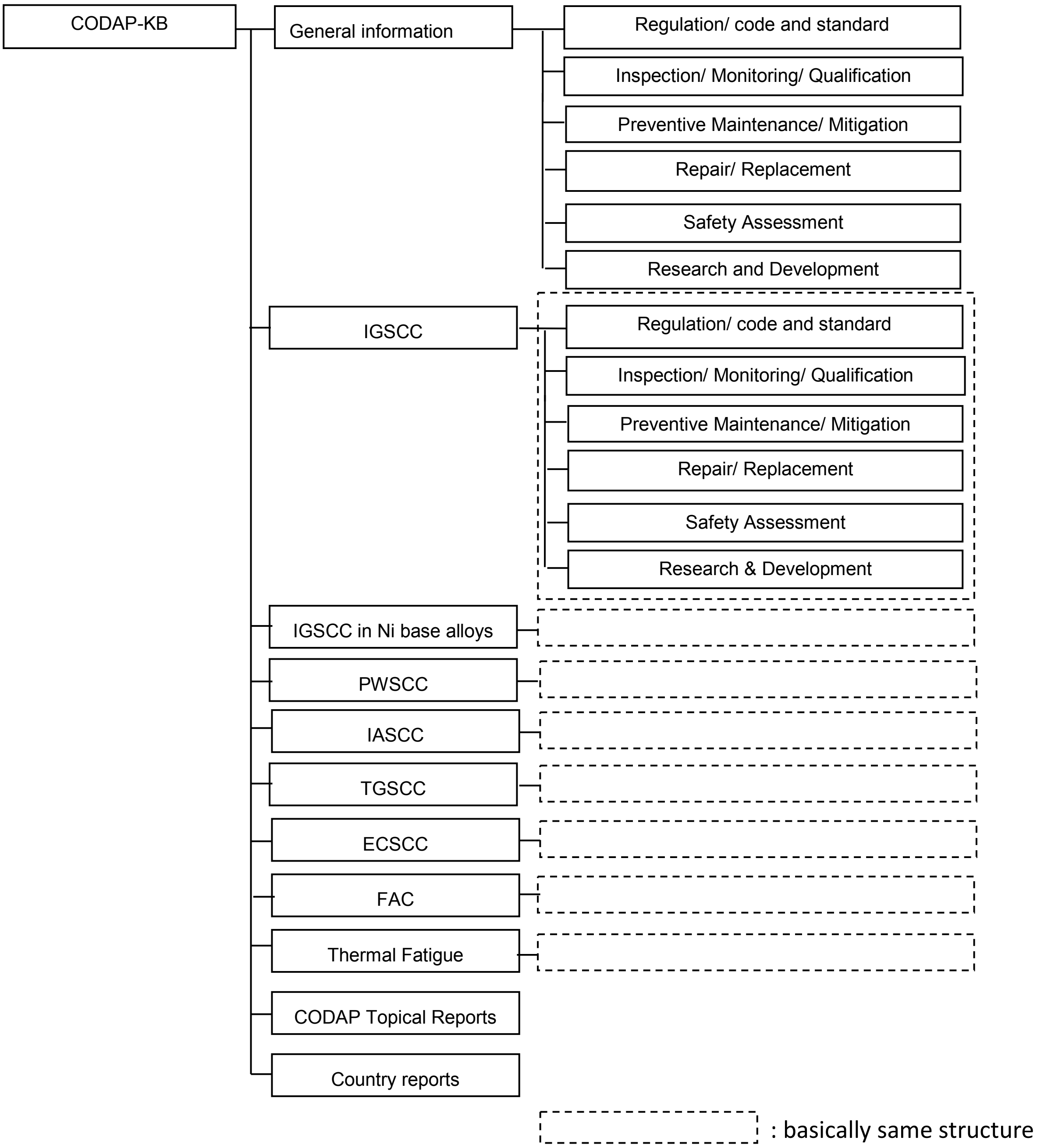
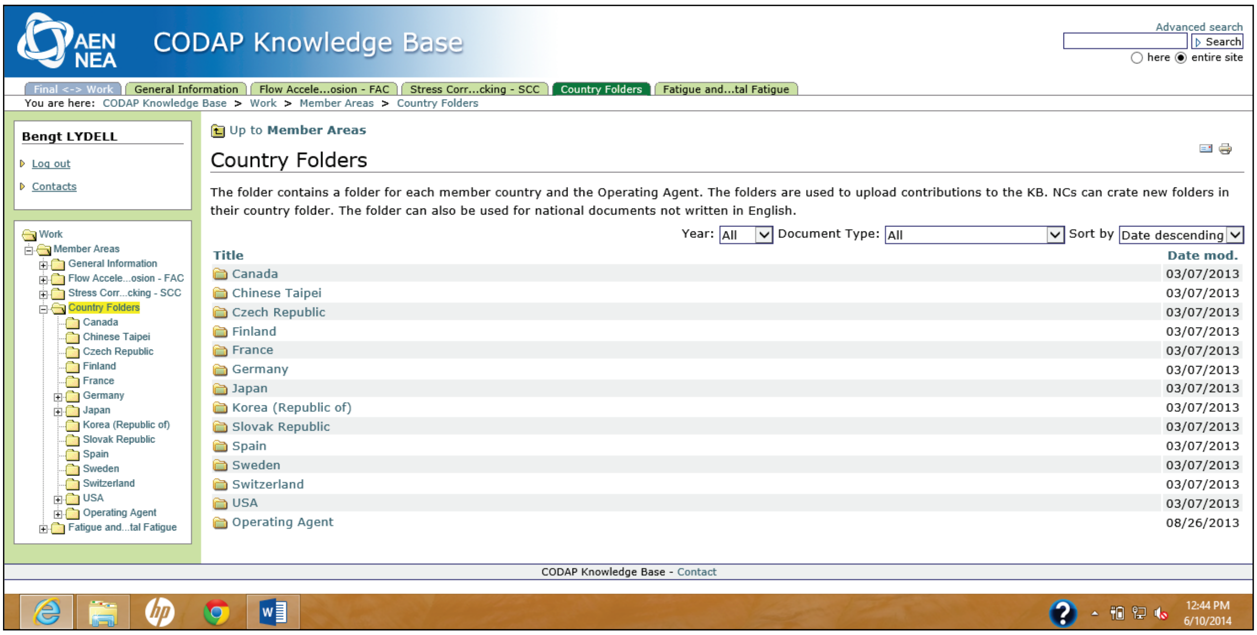


**Figure 6**: CODAP-KB Structure



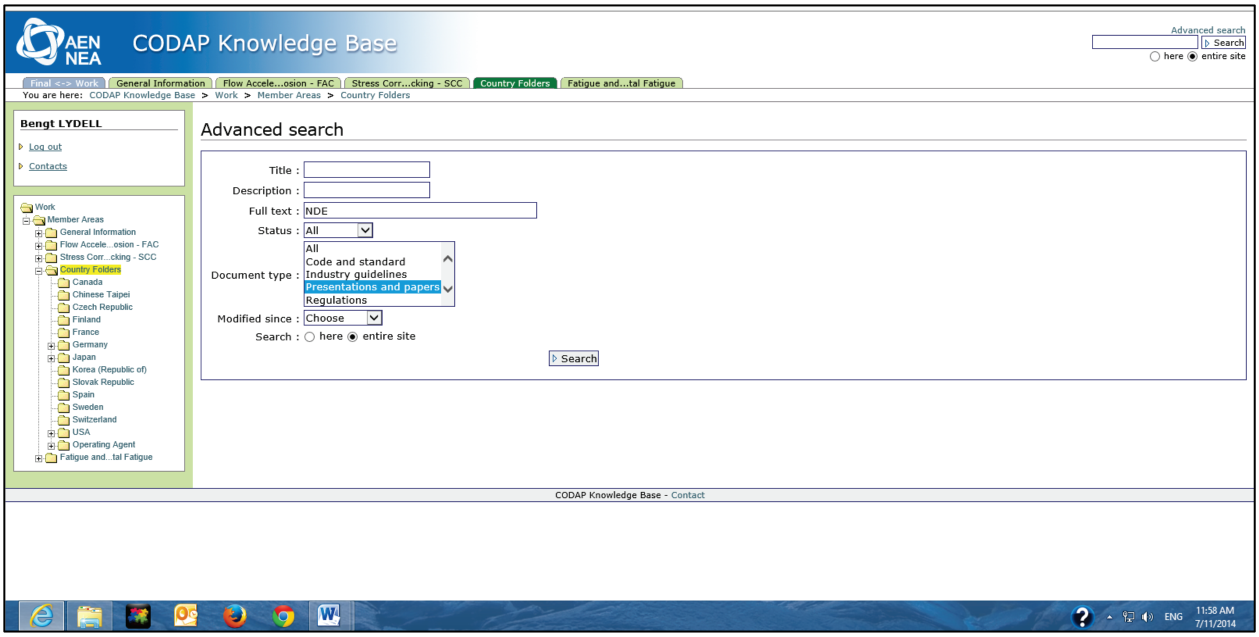
Country Folders

The folder contains a folder for each member country and the Operating Agent. The folders are used to upload contributions to the KB. NCs can crate new folders in their country folder. The folder can also be used for national documents not written in English.

Year: All Document Type: All Sort by Date descending

| Title | Date mod. |
|---|---|
| Canada | 03/07/2013 |
| Chinese Taipei | 03/07/2013 |
| Czech Republic | 03/07/2013 |
| Finland | 03/07/2013 |
| France | 03/07/2013 |
| Germany | 03/07/2013 |
| Japan | 03/07/2013 |
| Korea (Republic of) | 03/07/2013 |
| Slovak Republic | 03/07/2013 |
| Spain | 03/07/2013 |
| Sweden | 03/07/2013 |
| Switzerland | 03/07/2013 |
| USA | 03/07/2013 |
| Operating Agent | 08/26/2013 |

**Figure 7**: CODAP-KB Work Area

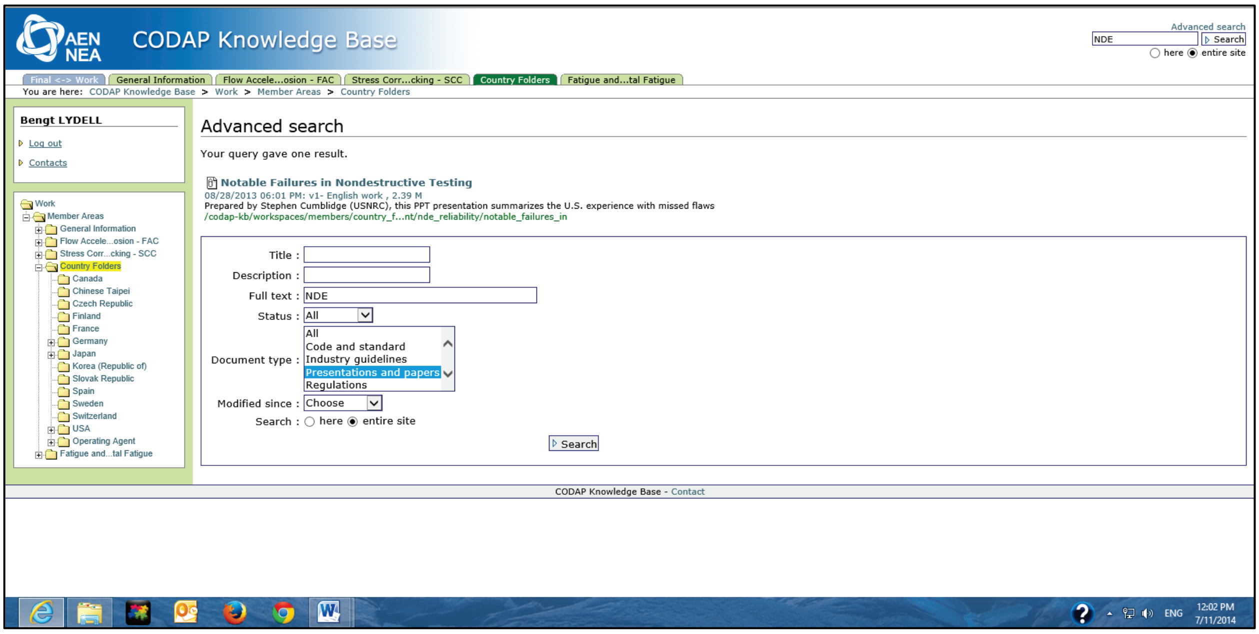


Advanced search

Title :
Description :
Full text : NDE
Status : All
Document type : All / Code and standard / Industry guidelines / [✓ Presentations and papers] / Regulations
Modified since : Choose
Search : ○ here ● entire site

Search

**Figure 8**: CODAP-KB Advanced Search Area



NDE ○ here ● entire site

You are here: CODAP Knowledge Base > Work > Member Areas > Country Folders

Bengt LYDELL

Advanced search

Your query gave one result.

Notable Failures in Nondestructive Testing
08/28/2013 06:01 PM: v1- English work , 2.39 M
Prepared by Stephen Cumblidge (USNRC), this PPT presentation summarizes the U.S. experience with missed flaws
/codap-kb/workspaces/members/country_f...nt/nde_reliability/notable_failures_in

Title :
Description :
Full text : NDE
Status : All
Document type : All / Code and standard / Industry guidelines / Presentations and papers / Regulations
Modified since : Choose
Search : ○ here ● entire site

**Figure 9**: An Example of a CODAP-KB Search

# 7. OPERATING EXPERIENCE INSIGHTS

The CODAP First Term Version of the Event Database includes approximately 4,700 records on metallic piping and non-piping metallic passive component failures from 356 reactor units representing ca. 10,500 commercial reactor-operating-years. Of the database content, 50% of the records relate to PWRs, 46% to BWRs, and 4% to PHWRs.[9] Chapter 7 addresses selected operating experience insights involving reactor coolant pressure boundary (RCPB) crack and leak events, primary water stress corrosion cracking (PWSCC) of PWR passive components, service water piping failures, socket weld failures, and NDE reliability.[10]

## 7.1 RCPB Crack and Leak Events

This section summarizes the field experience with BWR, PHWR and PWR primary water system (or reactor coolant pressure boundary, RCPB) cracks and leaks. The latter involves leak events that have occurred during operating modes other than cold shutdown; i.e., full power, low power, hot standby or hot shutdown. All at-power leak events have been detected early and resulted in early, controlled reactor shutdown. The leakages have been detected by leak detection systems Leakages during hot standby or hot shutdown have resulted in orderly cooldown to the cold shutdown state. In some cases these leaks have been discovered fortuitously when drywell (BWR) or containment (PWR) entry was made for some other purpose.

For the time period 2002-2014, Figure 10 summarizes the RCPB piping crack and leak event population. Figure 11 summarizes the RCPB non-piping passive component crack and leak event population. In Figure 10, an outlier (calendar years 2002 and 2003) refers to intergranular stress corrosion cracking (IGSCC) of Reactor Recirculation (RR) piping welds in Japanese BWR plants. This 2002-2003 Japanese experience involved relatively shallow (< 20% through-wall) cracks in cold worked austenitic stainless steel piping of Type AISI 316L All cracks were discovered during scheduled non-destructive examination. In Figure 11, an important sub-population relates to PWSCC of PWR reactor pressure vessel head penetrations (VHPs).

Figure 12 summarizes the operating experience involving RCPB piping leak events that occurred with the reactor in operating modes other than cold shutdown; i.e., full-/low-power, hot standby or hot shutdown. The operating experience is organized by cumulative number of events versus through-wall leak or flow rate threshold values for the period 1970 to 2014 and 1990-2014, respectively. The majority of events have involved very small (or perceptible) through-wall leaks. For the entire period covered by the CODAP event database (1970-2014), about 90% of primary water leak events have been below or well below $6\times10^{-2}$ kg/s, which corresponds to the Technical Specification limit for manual shutdown. Only a few events have produced significant RCPB through-wall flow rates above 1 kg/s (> 10 gpm), examples include the following events:

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[9] The PWR event population includes events at WWER reactors in Czech Republic, Finland and Slovak Republic. The PHWR event population includes events in Canadian and Korean (Republic of) plants.

[10] The operating experience review is current as of 30-November-2014.

- In December 1994, a small LOCA occurred due to a reactor coolant relief valve (RV) failure and resulting complications. The sequence of events leading up to the pressure boundary breach began with the RV opening due to a failed instrument air (IA) supply line. As a consequence of this initial IA line failure and the opening of the RC-RV, relief valves on the primary heat transport system bleed condenser lifted. After the initial opening, one of these RVs shut and began to chatter. The valve chattering caused stress in the RV inlet pipe and eventually led to the development and propagation of cracks in the lower elbow of the inlet pipe which caused the primary pressure boundary breach. This event occurred at a PHWR plant.

- In January 1993, with the reactor in hot shutdown, a failure of a vent line on the Residual Heat Removal (RHR) suction line off of the Reactor Coolant hot leg released water into the Containment Building in addition to a RHR relief valve that was opening prematurely. Investigation of the vent line determined a weld had been damaged by vibration during previous water hammer events. The mass flow rate through the broken pipe was estimated at ca. 10 kg/s.

- In November 1991, a reactor coolant leak at an instrument line fitting failed causing a forced reactor shutdown. The failed instrument line connected to the top of steam generator ‘A’ hot leg. The mass flow rate through the broken instrument line was estimated at ca. 6 kg/s. The root cause evaluation determined that the failed instrument line (part of the Reactor Vessel Level Indication System) was caused by an improperly installed compression fitting.

- In July 1998, a primary water leak resulted in manual reactor shutdown. The leak was on a DN25 line at a tee near a valve and resulted in the loss of heat transport (HT) inventory at the rate of approximately 3 kg/s. The fractured pipe section was cut out and submitted for immediate failure analysis. The line break was attributed to a high cycle fatigue failure caused by a positive displacement pump producing a constant source of flow-induced vibrations.

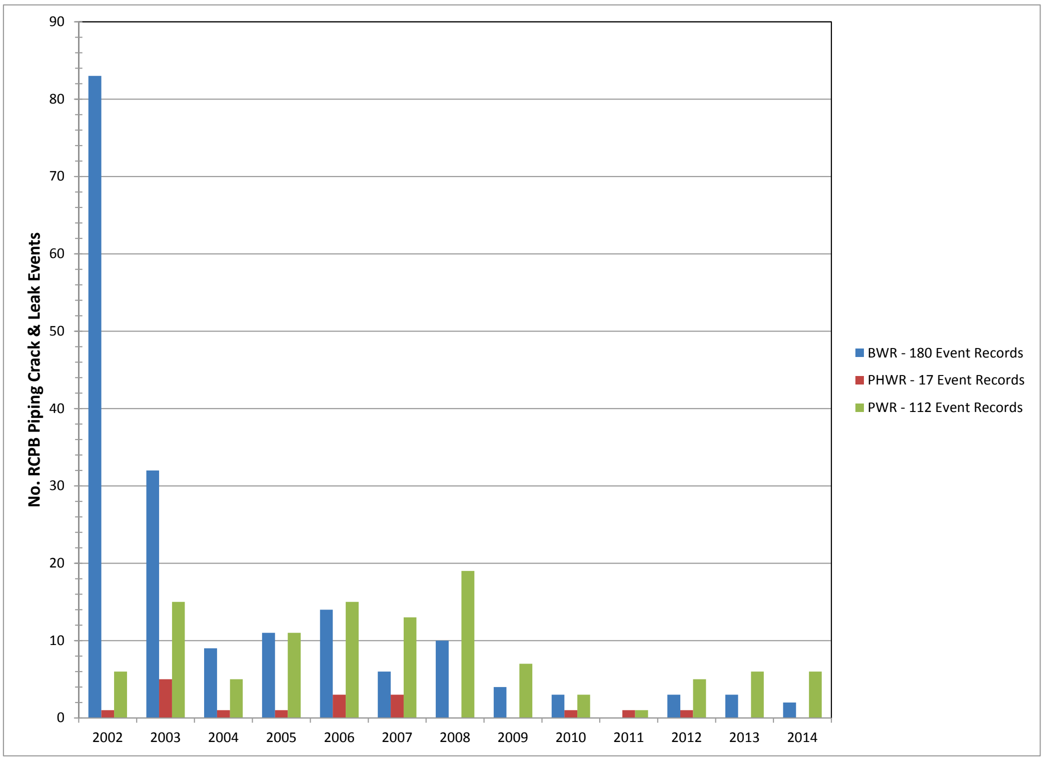

**Figure 10**: RCPB Piping Crack & Leak Events

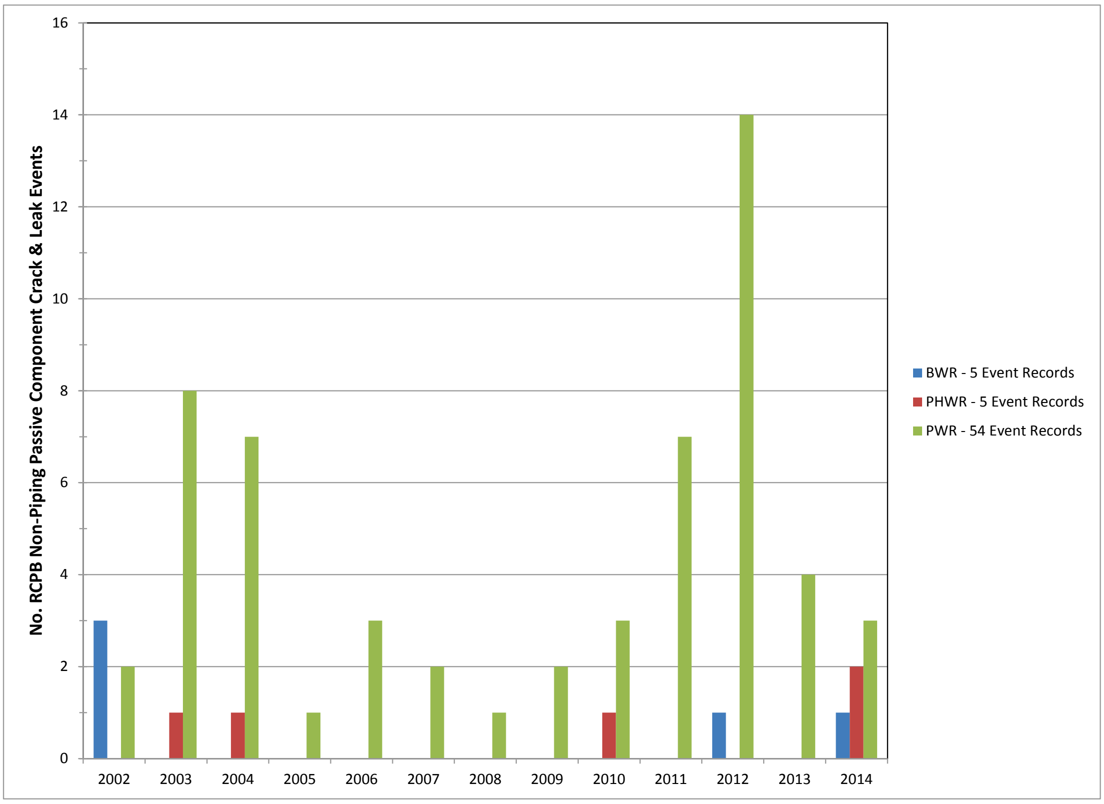

**Figure 11**: RCPB Crack & Leak Events Involving Non-Piping Passive Components

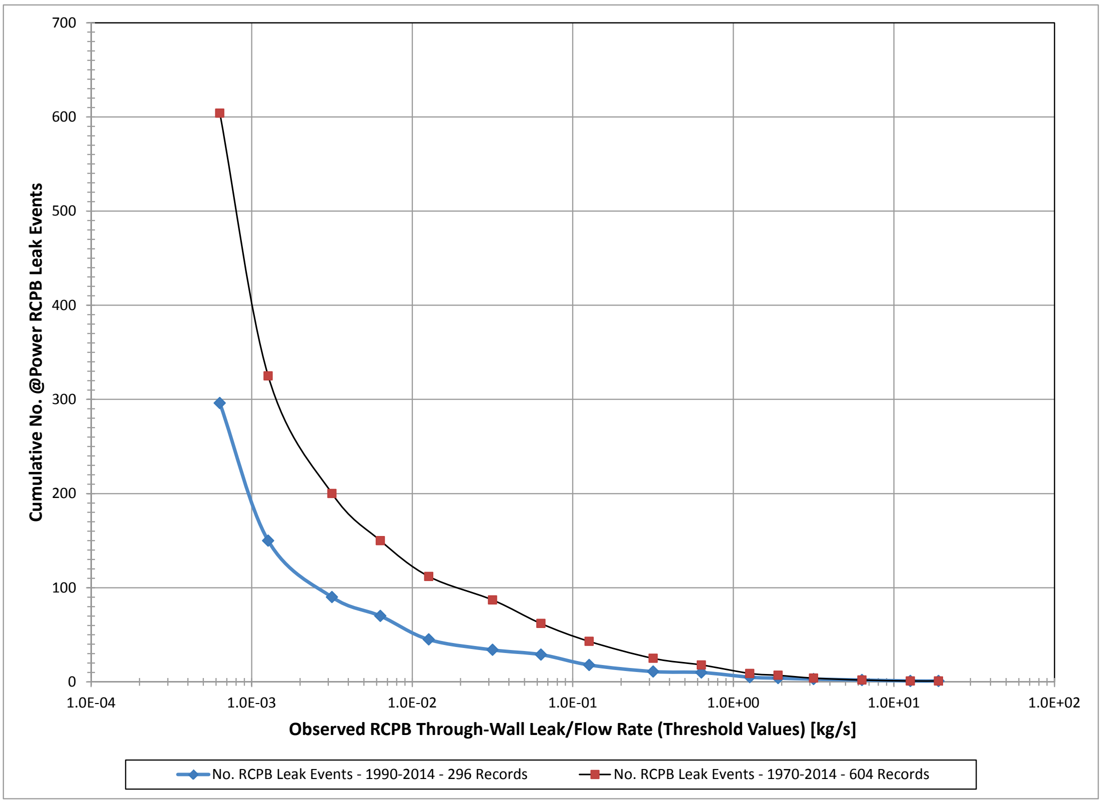

**Figure 12**: RCPB Piping @ Power Leak Events

## 7.2 Primary Water Stress Corrosion Cracking

Nickel-base alloys, particularly Alloy 600, and weld metals Alloy 82, 132 and 182, have proved to be susceptible to IGSCC in normal specification PWR primary water systems. This is commonly known as PWSCC. The history of the Alloy 600 IGSCC discovery is documented in Reference [17]. Available operating experience shows that temperature and fabrication induced residual stresses have a large influence on PWSCC in Alloy 600 weld metal. Examples of components affected include pressurizer, hot leg, cold leg, drain, and reactor coolant pump nozzle-to-safe end dissimilar metal welds (ASME XI Category B-F welds), penetrations welded to the reactor vessel and reactor vessel head and steam generator. Figure 13 is a summary of PWSCC records in the CODAP event database. The database contains over 300 records pertaining to PWSCC incidents in PWR primary circuits since the mid-1980s.

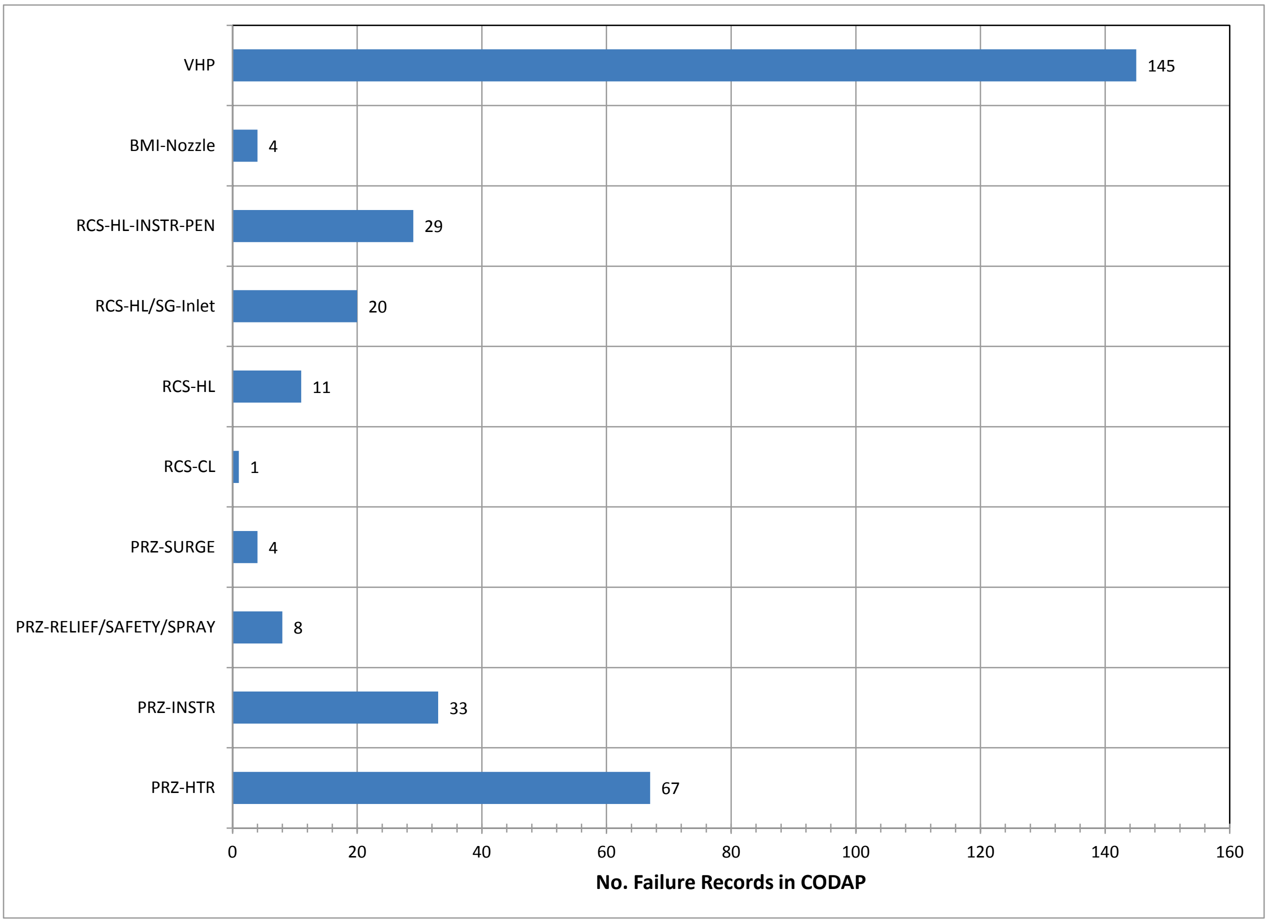

**Figure 13**: Summary of PWSCC Incidents in PWR Primary Circuits 1986-2014

Detection of PWSCC can be challenging because this form of cracking exhibits tight and complex branching in the nickel-base weld metal and forgings. With reference to Figure 13, examples of recent (2002-2014) PWSCC incidents include non-through-wall and through-wall flaws involving bottom-mounted instrument (BMI) nozzles and steam generator inlet nozzles at Japanese, French and U.S. plants. In all cases, these flaws have been identified during in-service inspection activities and they have resulted in expanded or unplanned outage work, including extensive root cause evaluations and operability evaluations. In the CODAP event database, four (4) PWSCC incidents involving BMI nozzles are:

- Japanese PWR Unit, January 2003: A possible indication of PWSCC (< 1 mm) in the base metal of BMI No. 48 was detected through eddy current testing (ET) from the nozzle inner diameter

(ID). The ET was performed prior to planned water jet peening of the nozzle ID. There have been no subsequent reports of detected indications in BMIs at the affected unit or any other Japanese plant.

- US PWR Unit, April 2003: Leakage from BMIs No. 1 and 46 was identified during walkdowns to support the utility's Boric Acid Corrosion Control Program. Non-destructive examination (NDE) did not reveal any other indications of PWSCC beyond the cracking in BMI nozzles No. 1 and 46.

- French PWR Unit, October 2011. Indications that were interpreted as PWSCC were detected via UT from the inside of the nozzles as part of the third 10-year ISI**.** There was no evidence of boric acid deposits on the bottom head during the second and third ISI interval. Electricité de France (EDF) expanded the requirement for internal UT inspection of BMIs to all reactor vessels in the French fleet.

- US PWR Unit, October 2013. The cause of the pressure boundary leakage was axial cracking in a sub-surface BMI nozzle J-groove weld flaw that extended into the nozzle to a length exceeding the J-groove weld leg thickness. The laboratory analysis of the boat sample suggests the weld flaw became wetted at some point during service which enabled concentration of environmental constituents that promoted PWSCC in the weld and nozzle materials. Leakage occurred once the axial cracking extended below the J-groove weld root.

In some Japanese and U.S. PWR plants the reactor coolant hot leg and cold leg are connected to the steam generator inlet/outlet nozzle, respectively, via dissimilar (Category B-F) welds of Alloy 82/132/182 weld material. Summarized in Figure 14 are PWSCC incidents (2007-2012) involving the steam generator (S/G) inlet nozzle dissimilar metal welds. This figure shows the measured crack depth of each individual cracking incident. Of the 20 incidents recorded in the CODAP event database, 19 incidents involved Japanese PWR plants and one event involved a U.S. reactor unit. The latter PWSCC incident occurred in 2012 and is of interest because of the extent of cracking and an apparent NDE deficiency:

- During the performance of work activities to support Alloy 600 dissimilar metal weld overlay work on the 'B' Reactor Coolant loop hot leg to the 'B' Steam Generator nozzle weld, two through-wall defects were identified. The workers noted a small amount of water seeping from the indications in the nozzle weld area. The indications were in the area of excavation that was being performed for the weld overlay project. Approximately 25 mm of weld material had been removed prior to the seepage being identified. The root cause evaluation determined the leakage developed due to PWSCC in a susceptible material (i.e. Alloy 82/182). After review of the fabrication records, it was further determined that the primary water stress corrosion cracks were caused by extensive ID weld repairs performed only on the 'B' Hot Leg nozzle. Of special noteworthyness, during the initial UT-examination, several axially oriented flaws went undetected by the manual conventional ultrasonic testing (UT) technique. The flaws were subsequently detected as a result of outside-diameter (OD) surface machining in preparation for a full structural weld overlay. A detailed assessment of the failure of the applied UT technique is documented in Reference [17]. According this reference, a number of critical factors may have combined in the failure to detect the axial flaws. The intent of the site-specific performance demonstration was to apply a modified version of a generic procedure for this examination orginally qualified by the US industry's Performance Demonstration Initiative (PDI). The North Anna qualification approach played a substantial role in this event.

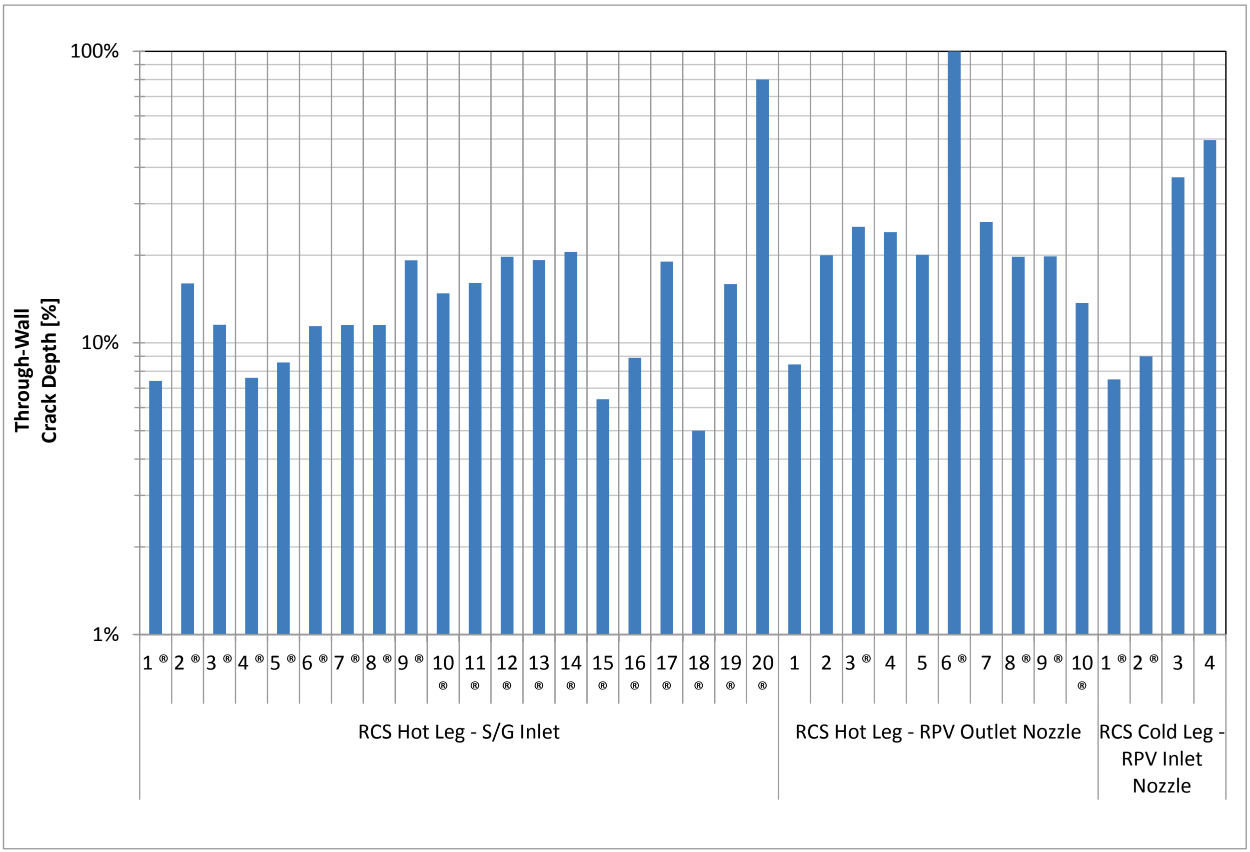

**Figure 14**: PWSCC Incidents Involving Reactor Coolant Cold Leg & Hot Leg Piping[11]

### 7.4 Service Water Piping Failures

The field experience with Service Water (SW) piping is abundant and includes non-through-wall flaws and through-wall flaws that have resulted in repair or replacement of affected pipe sections. The high safety significance associated with SW piping degradation and failures has warranted corrective actions to reduce both the frequency and potential consequences of operating events involving such degradation and failures. Limited to the German and US operating experience with SW piping, Figure 15 summarizes the failure data contained in the CODAP event database for the period 2002-2014. A detailed overview of the German experience with SW system piping and non-piping passive components is documented in Reference [18].

Service water piping systems carry cooling water to various heat exchangers throughout a power plant. It removes the heat from such auxiliary systems as component cooling heat exchangers, emergency diesel generators, containment coolers, lubrication oil coolers, room coolers, and chiller condensers. It consists of an intake structure for the cooling water, a distribution system within the plant and an outlet structure. Suction is taken from the ultimate heat sink (e.g., ocean, river, lake, or reservoir), heat is removed via various heat exchangers, and the water is discharged back to the ultimate heat sink (UHS) or self-contained UHS (e.g., spray cooling pond or cooling tower). With an infinite supply of water, the SW systems represent an important potential flood source. Relative to the in-plant SW piping design and routing, there are four basic types of SW system designs: 1) open loop system, 3) open recirculating system with a self-contained ultimate heat sink such as spray cooling pond or a cooling tower, 3) closed

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[11] Superscript "®" indicates a "repair weld," refer to the Glossary of Terms for a definition.

loop system, and 4) closed loop system with a self-contained UHS. Each of the four system designs has advantages and disadvantages relative to SW pipe aging characteristics.

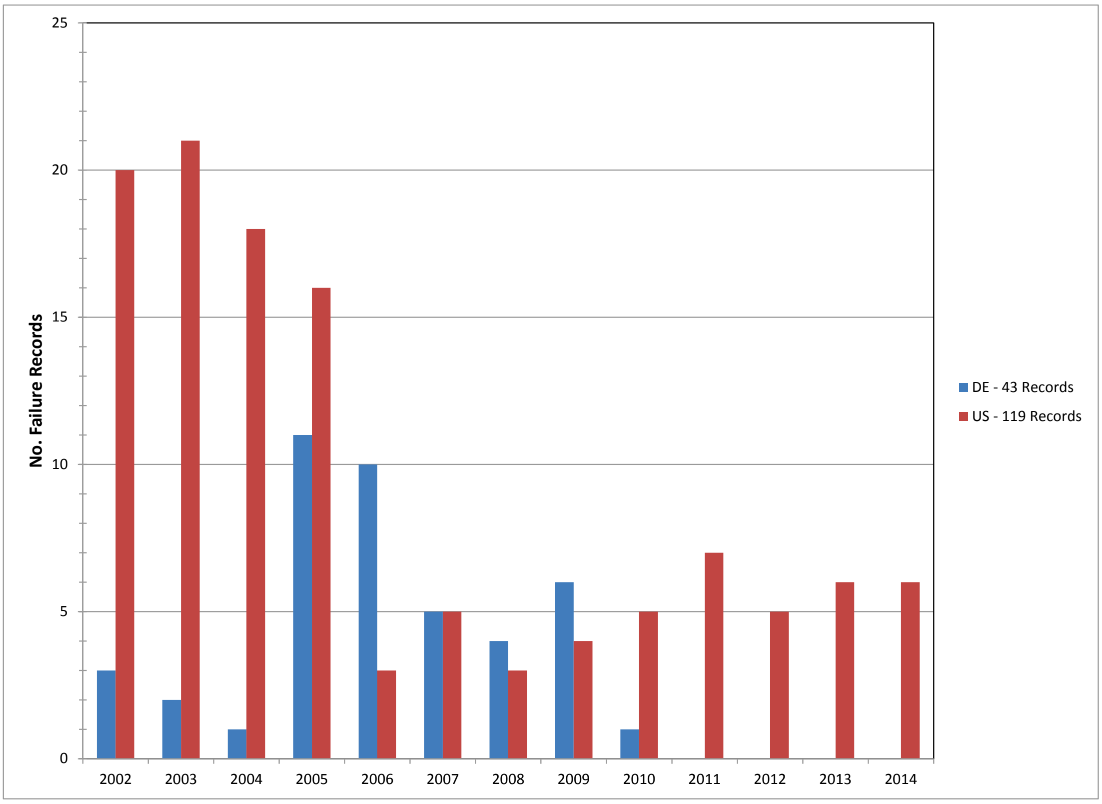

**Figure 15**: SW Piping & Non-Piping Passive Component Failures

The SW piping system operates under corrosive and erosive service conditions. The system is prone to degradation involving localized pitting and wall thinning and through-wall leaks. The rate of material degradation differs significantly across the plant population, however. Factors influencing the rate of degradation include:

- <u>System Design</u>. The service conditions tend to be somewhat more aggressive in open or straight-through systems than the closed systems. The latter type is more amenable to chemical treatment programs.

- <u>Piping Material Selection</u>. Compared to other in-plant process and standby safety systems, the operating environment in SW piping is aggressive. However, the rate of degradation is strongly correlated with the chosen type of piping material. Some plants in Chinese-Taipei, Sweden and the US have made extensive piping replacements using high-performance stainless steel to mitigate or even eliminate corrosion susceptibilities. Relative to austenitic stainless steels of Type 304 or 316, the high-performance stainless steels are defined as those with substantially higher chromium, molybdenum and nitrogen content. Listed below are typical SW piping materials:

  - Carbon steel (e.g., A-106 Gr. B).

- Stainless steel (Type 304 or 316); mainly used for small- to medium-diameter (≤ NPS8) piping. As susceptible to microbiologically influenced corrosion (MIC) as carbon steel, however.

- “High performance stainless steels” developed specifically for salt water systems.

- Nickel-copper alloys.

- Lined carbon steel piping; many plants use cement-, rubber- or epoxy/PVC-lined carbon steel piping where the service environment is erosive. Lining failure due to thermal cycling and improper welding frequently causes localized pitting and pinhole leaks, however.

In the U.S., Generic Letter 90-05 [19] develops the Nuclear Regulatory Commission position on temporary non-Code repairs of moderate-energy piping systems. Such repairs are applicable until the next scheduled outage exceeding 30 days, but no later than the next scheduled refueling outage. The guidance in the Generic Letter applies when a flaw is detected during plant operation. If a flaw is detected during a scheduled shutdown, a code repair is required before plant restart. Non-Code approaches must be submitted for review and evaluation to the NRC on a case-by-case basis for consideration before a relief request is granted. The principles of Generic Letter 90-05 have been adopted by the regulatory authorities of Chinese-Taipei [20] and Spain. The Generic Letter 90-05 includes an evaluation guideline on temporary repairs. This guideline consists of four parts:

1. Flaw detection during plant operation and impracticality determination. “Impractical” means that affected section of piping cannot be isolated for completing a Code repair within the Technical Specification Limiting Condition for Operation (LCO) without a plant shutdown. For example an LCO may prescribe that an affected SW train must be restored to operable status within 72 hours or be in at least hot standby within the next 6 hours.

2. Root cause determination and flaw characterization. This determination should include a positive identification of root cause and an identification of the most susceptible locations in the piping system.

3. Flaw evaluation. The flawed piping should satisfy the criteria of one of two approaches, the “through-wall flaw” approach or the “wall thinning” approach for non-through wall flaws.

4. Augmented inspection. If the flaw is evaluated and found acceptable, the plant operator should perform an augmented inspection via UT or RT to assess the overall degradation of the system. The augmented inspection, performed within 15 days of detection of the flaw, which results in a temporary non-Code repair, is part of the relief acceptance criteria of the repair. The inspection should be performed for at least the 5 most susceptible (and accessible) locations.

## 7.5 Socket Weld Failures

A socket weld is a pipe attachment detail in which a pipe is inserted into a recessed area of a valve, fitting (e.g., elbow or tee), or flange. In contrast to butt welds, socket welds are mainly used for small-diameter piping of nominal size 50 mm or less. Fatigue resistance is lower than that in butt-welded construction due to the use of fillet welds and fitting geometry. The CODAP event database includes ample information on socket weld failures. Socket welds are used extensively in safety-related piping systems. Table 5 includes a sample of socket weld populations in primary system piping. The information has been obtained through reviews of fabrication isometric drawings.

Socket weld design requirements are defined in the “ASME Code for Pressure Piping” [21]. This Code specifies minimum welding dimensions for socket welds. An important dimensional parameter is the gap between pipe and fitting prior to welding. The failure data includes numerous instances where insufficient gap (or “pull-back”) has contributed to weld failure. National “technical requirements manuals” (TRMs) typically include additional details on socket weld dimensional requirements. As one example, the Swedish Nuclear Power Companies have jointly developed a TRM entitled “Technical Regulations for Mechanical Equipment” [22] which is an “implementation document” that interprets the relevant national regulatory requirements. Sections 3.3.8 and 4.1.3.2 of this particular TRM identifies the specific requirements that apply to the installation of socket welds in safety-related piping systems.

**Table 5: An Example of Code Class 1 Socket Weld Populations**

| ASME III Class 1 Small-Bore Piping Systems | | | | | |
|---|---|---|---|---|---|
| Plant / Plant Type | Date of Commercial Operation | Weld Population | | | Pipe Size |
| | | Socket Welds | Butt Welds | Total | |
| Plant A / WH 4-Loop | Sep-85 | 872 | 175 | 1047 | ≤ DN25 |
| Plant B / WH 4-Loop | Aug-87 | 828 | 181 | 1009 | ≤ DN25 |
| Plant C / WH 4-Loop | Jul-88 | 933 | 136 | 1069 | ≤ DN25 |
| Plant D / WH 4-Loop | Oct-88 | 962 | 129 | 1091 | ≤ DN25 |
| Plant E / WH 4-Loop | Dec-84 | 77 | Not Determined | -- | 25 ≤ DN < 100 |
| Plant F / WH 2-Loop | Jun-74 | 345 | Not Determined | -- | ≤ DN50 |
| Plant G / WH 4-Loop | Aug-74 | 433 | 195 | 628 | ≤ DN50 |
| Plant H / WH 4-Loop | Aug-76 | 333 | 96 | 429 | ≤ DN50 |
| Plant I / WH 4-Loop | Aug-90 | 150 | 300 | 450 | ≤ DN50 |
| Plant J / WH 4-Loop | Aug-88 | 49 | 182 | 231 | ≤ DN50 |
| Plant K / WH 4-Loop | Jun-89 | 59 | 190 | 249 | ≤ DN50 |

### *7.5.1 Socket Weld Failure Data*

There have been frequent occurrences of high-cycle fatigue failures of socket welded connections in safety related piping systems. Limited to the French (Reference [23]) and US operating experience (CODAP), respectively, Figure 16 summarizes socket weld failure data for the period 1990-2014.

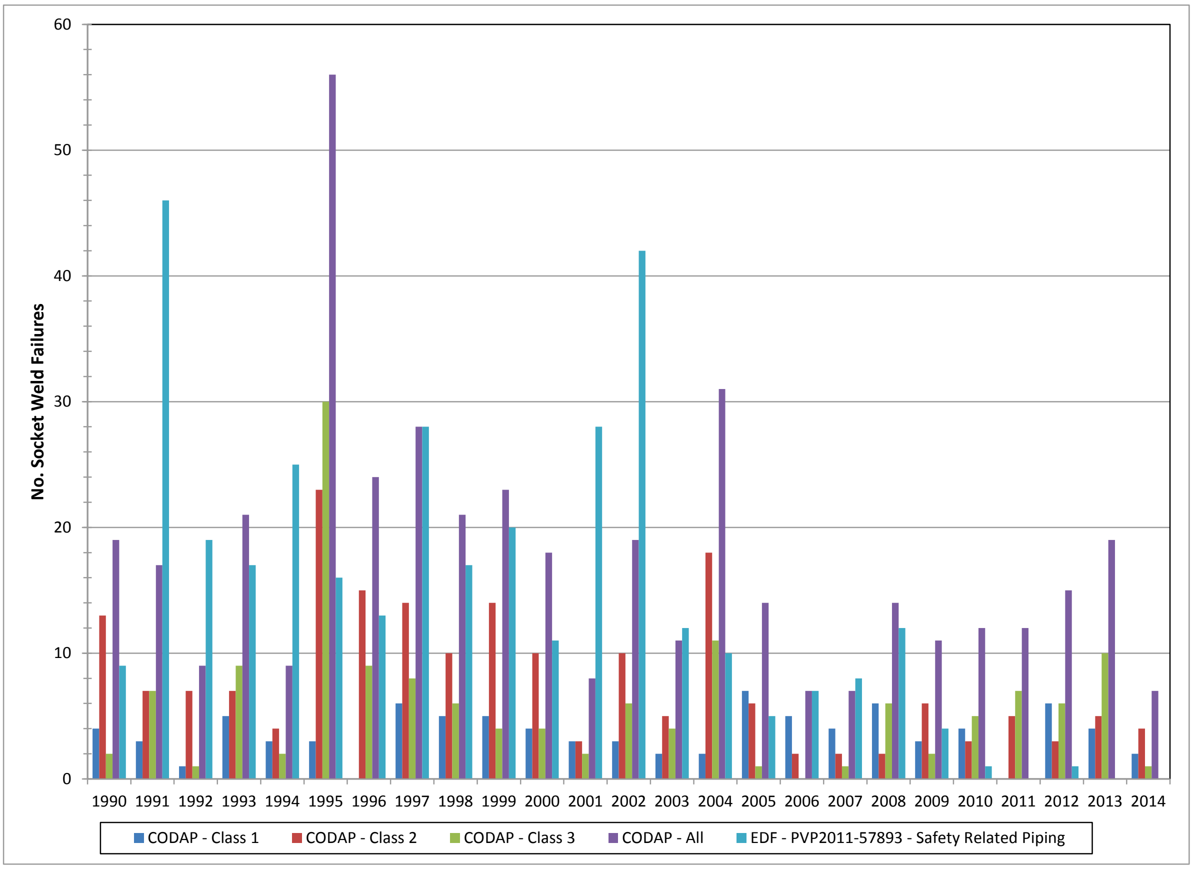

**Figure 16: Selected Socket Weld Failure Data (1990-2014)**

### *7.5.2 Socket Weld Reliability and Integrity Management*

This section compares and contrasts certain aspects of the French and U.S. industry practices with respect to socket weld reliability and integrity management (RIM). In 2002 the French regulatory authority, Autorité de sûreté nucléarie (ASN) issued a directive concerning socket weld integrity (DGSNR-BCCN/OT/VF No. 020406 [24]). According to this directive, socket welds not meeting the requirements for weld dimensions and/or weld integrity as specified by the RCC-M Code [25] "…shall be replaced with butt welds." In response to the directive by ASN, EDF implemented a systematic socket weld integrity program for all of its Class 900 MWe PWR plants [23].

In the US, NUREG-1801 [25] provides a technical basis for determining the adequacy of aging management programs (AMPs) for license renewal. Section XI.M35 of this reference augments the requirements in ASME Section XI, 2004 Edition (Rules for In-service Inspection of Nuclear Power Plant Components). According to Table IWB-2500-1 of the ASME Code, an external surface examination of small-bore Class 1 piping should be included for piping less than DN100. Other ASME Code provisions exempt from examination piping of size DN25 and smaller. This program is augmented to include piping from DN25 to less than DN100. Also, Examination Category B-P requires system leakage of all Class 1 piping.

According to the NRC, for a one-time inspection to detect cracking resulting from thermal and mechanical loading or intergranular stress corrosion of full-penetration welds, the inspection should be a volumetric examination. For a one-time inspection to detect cracking in socket welds, the inspection should be either a volumetric or opportunistic destructive examination. Opportunistic destructive examination is performed when a weld is removed from service for other considerations, such as plant modifications. A sampling basis is used if more than 1 weld is removed. These examinations provide additional assurance that either aging of small-bore ASME Code Class 1 piping is not occurring or the aging is insignificant, such that a plant-specific aging management program (AMP) is not warranted. The one-time inspection is applicable to small-bore ASME Code Class 1 piping and systems less than DN100 and greater than or equal to DN25. The program includes pipes, fittings, branch connections, and all full and partial penetration (socket) welds.

This program is applicable to systems that have not experienced cracking of ASME Code Class 1 small-bore piping. This program can also be used for systems that experienced cracking but have implemented design changes to effectively mitigate cracking. (Measure of effectiveness includes (1) the one-time inspection sampling is statistically significant;(2) samples will be selected as described in Element 5, Monitoring and Trending below; and (3) no repeated failures over an extended period of time.) For systems that have experienced cracking and operating experience indicates that design changes have not been implemented to effectively mitigate cracking, periodic inspection is proposed, as managed by a plant-specific AMP. Should evidence of cracking be revealed by a one-time inspection, periodic inspection is implemented using a plant-specific AMP. If small bore piping in a particular plant system has experienced cracking, small bore piping in all plant systems are evaluated to determine whether the cause for the cracking affects other systems.

## 7.6 NDE Failures

The ASME Boiler and Pressure Vessel Code Section XI, “Rules for Inservice Inspection of Nuclear Power Plant Components” [15] provides requirements for examination, testing, and inspection of components and systems, and repair/replacement activities in a nuclear power plant. The mandatory Appendix VIII of ASME Section XI provides requirements for performance demonstration (PD) for ultrasonic examination procedures, equipment, and personnel used to detect and size flaws. When ASME Section XI was first issued in 1971, the ultrasonic inspection techniques specified were adapted from manufacturing practices and were based on previous experience with fatigue cracking. The ultrasonic examination rules were prescriptive and had not been evaluated on nuclear reactor service-induced degradation mechanisms. The reliability of the nondestructive examinations (NDE) that were specified by Section XI was not quantified via testing. Instead, the initial premise of Section XI was that reliable ultrasonic testing (UT) could be ensured through detailed rules [27].

Based on early field experience, the failure of ISI to detect leaking cracks raised concerns regarding the effectiveness of ultrasonic testing being conducted at nuclear power plants and showed that improvements in inspection requirements were needed. In response, the NRC sponsored R&D to assess nondestructive examination (NDE) reliability. This research showed that prescriptive requirements could not be written to sufficiently accommodate the diversity of power plant materials, field conditions, and flaw degradation processes typically encountered. It was subsequently decided that a performance-based testing approach would be the most effective means for achieving the needed improvements in NDE reliability.

In 1991 the US utilities formed the Performance Demonstration Initiative (PDI) to implement the then current performance demonstration requirements of the ASME Code, Section XI, Appendix VIII “Performance Demonstration for Ultrasonic Examination Systems.” The PDI designated the Electric Power Research Institute (EPRI) Nondestructive Examination Center to be the Performance Demonstration Administrator (PDA).

The CODAP event database captures NDE failures in detecting pre-existing flaws before exceeding acceptance criteria. In the database passive component failure information is recorded in a tiered manner. First, basic failure information is recorded to address the most fundamental information about an event and this includes a free-format event narrative that describes the sequence of events, including plant response, consequence, in-plant location of failed component, dimensional data, and component type. This is followed by recording the known ISI history, including date when the failed component was last inspected, method of NDE qualification if a qualified method had been used, and any NDE performance deficiencies or failures. Finally, details about the service environment (e.g., water chemistry, stresses, pressure and temperature) are recorded as a lead-in to details from root cause evaluations (flaw data, chemical composition of material, results of metallographic examinations, apparent and underlying causes of material degradation). When NDE fails to detect leaking cracks one or more of the following factors are present:

- A rejectable flaw indication is determined to be acceptable for continued operation. This could be due to misinterpretation of NDE results.

- Use of improperly qualified NDE technique.

- Poor implementation of ASME Appendix VIII.

- A qualified Appendix VIII procedure misses a flaw.

Summarized in Figure 17 is the NDE failure population in the CODAP event database. Examples of recent (2002-2014) NDE failures include the previously addressed occurrence at a U.S. plant (Section 7.2) and the following selected events:

- US PWR Unit, April 2014. While performing planned inspections of Reactor Coolant System piping welds, two flaw indications were identified on a 1.5 inch High Pressure Safety Injection Line connection to the Reactor Coolant System piping (cold leg). After confirmatory inspections and evaluation, one of the two flaw indications was determined to not meet the acceptance criteria specified in ASME Section XI. This flaw was missed during the previous refueling outage as a result of a probable skill-based human performance error. The flaw was detected during normal inspections required by the NDE Augmented Examination program, which is driven by EPR MRP-146 ("Thermal Fatigue in Normally Stagnant Non-Isolable Reactor Coolant System Branch Lines") [28]. Non-isolable branch lines connected to the NC system are susceptible to high cycle thermal fatigue if exposed to specific operational conditions and configurations. Examples of susceptible locations are horizontal lines where in-leakage past a valve is present and lines see turbulent swirl penetration from adjacent piping flow. Initial MRP-146 inspections were performed in 2008 and did not include the area where the flaw was discovered.

- US PWR Unit, November 2013. Following a controlled shutdown in response to a RCPB leak, visual inspection confirmed that the leak was located on a High Pressure Injection Line. The root cause evaluation determined that a crack-like indication in the failed location had existed since 2011. Furthermore, the root cause evaluation concluded that inadequate procedural guidance existed for the conduct of Augmented Examinations and appropriate disposition of UT examination results where conditions limited the weld volume that could be examined. A UT limitation is defined as any obstruction or condition that limits the extent of angle beam scanning or limits the extent of required coverage using straight beam scanning. When adequate weld volumes could not be examined on the nozzle safe end-to-pipe butt weld, no procedural guidance provided weld volume acceptance criteria or directed these limitations to be entered into the corrective action program for evaluation. During the root cause investigation, metallurgical analysis documented that the crack propagated over several operating cycles. Historical NDE data revealed that the crack was visible in existing radiographs. Had the failed weld volume been adequately interrogated, the crack would have been identified before propagating through wall. The licensee reviewed the results of the previous UT examination performed in 2012 using a NDE procedure and found no reportable indications. However, in 2011, the licensee performed a radiographic examination specifically to check the condition and position of a thermal sleeve. The focus of the review was limited to that area; however, the safe end area containing cracked weld was incidentally visible on the film. Following the current event, the licensee re-reviewed the 2011 radiographic film and a crack-like indication was identified in the side wall image of the weld at approximately the same location as corresponding to the current crack location. From the re-review of the film, this crack-like indication appeared to be approximately 50% through-wall.

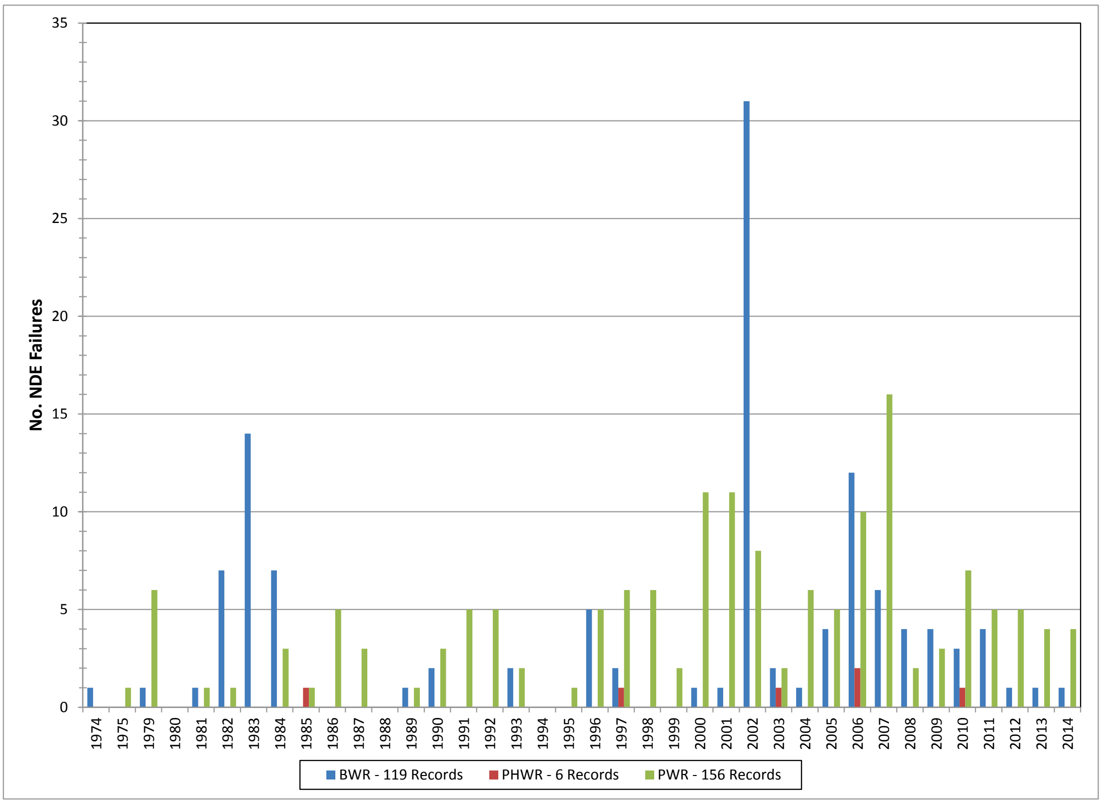

**Figure 17: NDE Failure Population in CODAP Event Database**

# 8. DATABASE ACCESSIBILITY

The CODAP Terms and Conditions contain statements on the use of data within or outside CODAP and on the handling of proprietary information. The Event Database is a restricted database and its access is limited to participating organisations that provide input data. The database is available on the Internet via a secure server located at the OECD-NEA Headquarters.

It has been recognised by the Project Review Group that many member organisations will want to pass on the CODAP database to their consultants for use in specific projects, and suchlike. For this purpose a non-confidential version of the CODAP database will be made available for use by consultants for a limited period of time. Before supplying a non-confidential version the member organisation making the request must provide the National Coordinator with written proof that the intended recipient of the non-confidential version of the database has agreed to comply with the confidentiality terms and conditions of the project.

# 9. CONCLUSIONS & FUTURE PLANS

CODAP is the continuation of the 2002–2011 "OECD/NEA Pipe Failure Data Exchange Project" (OPDE) and the Stress Corrosion Cracking (SCC) Working Group of the 2006–2010 “OECD/NEA SCC and Cable Ageing project” (SCAP). OPDE was formally launched in May 2002. Upon completion of the 3rd Term (May 2011), the OPDE project was officially closed to be succeeded by CODAP. SCAP was formally launched in June 2006 and officially closed with an international workshop held in Tokyo in May 2010. Following the completion of the SCAP project, its SCC Working Group participants were interested in some form of continuation and a new project was formed in 2011 by combining OPDE and SCAP-SCC into the “Component Operational Experience, Degradation & Ageing Programme” (CODAP).

## 9.1 Conclusions and Recommendations

During the first term the original objectives of the project were achieved and an operational web-based database was launched successfully. The PRG also implemented a web-based Knowledge Base (KB) intended to provide a source of information on technical issues related to all the failure mechanisms covered by the Event Database. The type of information collected includes regulations/codes and standards, and relevant documents on national activities in the areas of inspection/monitoring/qualification, preventive maintenance/mitigation, repair/replacement, safety assessment, and R&D. The information is both of a general nature and also more specific for the different degradation mechanisms. The KB is intended to provide a source of systematically organized information for the project members. In addition to the web-based event database and the KB, the PRG produced two topical reports intended for dissemination to interested parties within the international nuclear safety community.

The key objectives of CODAP are to encourage and support the multilateral exchange of operating experience data on metallic piping components and non-piping passive components. As indicated in Sections 5 (CODAP Event Database) and 7 (Operating Experience Insights), the current content of the database has a strong U.S. bias. A recommendation for the second term (2015-2017) of the project is to put in place operating procedures and processes whereby future national data submissions are commensurate with the number of operating reactors. Furthermore, in-depth database applications will be pursued to investigate the correlations between reported degradation and failure events versus piping system design modifications, degradation mitigation practices and NDE qualification.

It is equally important to put in place a process to capture legacy information concerning significant events. In the context of CODAP, the term “significant” implies both significant unexpected structural degradation or failure and events that have prompted significant regulatory action. Database completeness strongly affects the possibilities to perform advanced database applications.

## 9.2 Planned Activities Beyond 2014

The PRG recognizes that there are a multitude of future challenges concerning the response to environmental degradation of passive components in heavy water and light water reactor operating environments. It is important to ensure that the almost five decades of operating experience insights be preserved and made readily available to future generations of material scientists, structural engineers and

PSA engineers. In planning for activities beyond 2014 questions concerning the effectiveness of degradation mitigation processes and NDE reliability needs to be addressed, One way of doing so is to actively monitor any perceived or actual trends and patterns in the worldwide operating experience data that is fed back to the CODAP event database.

The PRG has prepared Terms & Conditions for the 2nd Term (2015-2017) of CODAP. The second term of the project places an emphasis on two aspects of operating experience data exchange and analysis. First, to encourage active data submissions by the PRG membership, an improved web-based database structure will be implemented. A detailed database improvement plan was presented at the CODAP08 PRG meeting in December 2014. Second, continued database applications will be pursued through an expanded program to develop topical report.

# 10. REFERENCES

[1] U.S. Nuclear Regulatory Commission, Investigation and Evaluation of Cracking in Austenitic Stainless Steel Piping of Boiling Water Reactor Plants, NUREG-75/067, Washington, DC, 1975.

[2] U.S. Nuclear Regulatory Commission, Investigation and Evaluation of Cracking Incidents in Piping in Pressurized Water Reactors, NUREG-0691, Washington, DC, 1980.

[3] Brown, E.J., Erosion in Nuclear Power Plants, AEOD/E4-16, Office for Analysis and Evaluation of Operational Data, U.S. Nuclear Regulatory Commission, Washington, DC, 1984.

[4] Cragnolino, G., Czajkowski, C., and Shack, W.J., Review of Erosion-Corrosion in Single-Phase Flows, NUREG/CR-5156, U.S. Nuclear Regulatory Commission, Washington, DC, 1988.

[5] IAEA, Corrosion and Erosion Aspects in Pressure Boundary Components of Light Water Reactors, Proc. Specialist Meeting Organized by the IAEA, IWG-RRPC-88-1, Vienna, Austria, 1990.

[6] OECD Nuclear Energy Agency, Experience with Thermal Fatigue in LWR Piping Caused by Mixing and Stratification, Specialist Meeting Proceedings, NEA/CSNI/R(98)8, Issy-les-Moulineaux, France, 1998.

[7] U.S. Nuclear Regulatory Commission, Reactor Safety Study. An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants, WASH-1400 (NUREG-75/014), Washington, DC, 1975.

[8] OECD Nuclear Energy Agency, OECD/NEA Piping Failure Data Exchange Project (OECD/NEA OPDE), Final Report, NEA/CSNI/R(2012)16, Issy-les-Moulineaux, France, 2012.

[9] OECD Nuclear Energy Agency, Technical Basis for Commendable Practices on Ageing Management – SCC and Cable Ageing Project (SCAP), Final Report, NEA/CSNI/R(2010)5, Issy-les-Moulineaux, France, 2010.

[10] OECD Nuclear Energy Agency, OECD/NEA Component Operational Experience, Degradation & Ageing Programme, Database Coding Guideline & User Manual, Revision 1, CODAP-PR01, Issy-les-Moulineaux, France, 2013.

[11] OECD Nuclear Energy Agency, OECD/NEA Component Operational Experience, Degradation & Ageing Programme, Database Applications Handbook, CODAP-PR05, Issy-les-Moulineaux, France, 2013.

[12] IAEA, Safety Glossary. Terminology Used in Nuclear Safety and Radiation Protection, STI/PUB/1290, Vienna, Austria, 2007.

[13] IAEA, Assessment and Management of Ageing of Major Nuclear Power Plant Components Important to Safety: BWR Pressure Vessel Internals, IAEA-TECDOC-1471, Vienna, Austria, 2005.

[14] IAEA, Assessment and Management of Ageing of Major Nuclear Power Plant Components Important to Safety: PWR Pressure Vessel Internals, IAEA-TECDOC-1119, Vienna, Austria, 1999.

[15] American Society of Mechanical Engineers, 2007 ASME Boiler and Pressure Vessel Code, Section XI: Rules for Inservice Inspection of Nuclear Power Plant Components, 2008a Addenda, New York, NY, July 2008.

[16] OECD Nuclear Energy Agency, Knowledge Transfer and Management of Operating Experience, NEA/CNRA/R(2012)1, Issy-les-Moulineaux, France, 2012.

[17] Combrade, P., Ford, P. and Nordmann, F., Key Results from Recent Conferences on Structural Materials Degradation in Water Cooled Reactors, A.N.T. International, Mölnlycke, Sweden, December 2010.[12]

[18] Anderson M.T. et al, Final Assessment of Manual Ultrasonic Examinations Applied to Detect Flaws in Primary System Dissimilar Metal Welds at North Anna Power Station, PNNL-22553, Pacific Northwest National Laboratory, Richland, WA, March 2014.

[19] Elmas, M., Reck, H. and von der Cron, D., Betriebserfahrung mit Komponenten der sicherheitstechnisch wichtigen Nebenkühlwassersysteme in deutschen Analgen mit DWR und SWR, GRS-A-3634, Gesellschaft für Analgen- und Reaktorsicherheit, Cologne, Germany, February 2012.

[20] U.S. Nuclear Regulatory Commission, Guidance for Performing Temporary Non-Code Repairs of ASME Code Class 1, 2 and 3 Piping, Generic Letter 90-05, Washington, DC, 1990.

[21] Ting, K. And You, J.S., "The Experiences of Non-Code Repairs for Nuclear Safety-Related Piping in Taiwan," Nuclear Engineering and Design, **214**:83-89, 2002.

[22] American Society of Mechanical Engineers, Process Piping. ASME Code for Pressure Piping, B31, ASME B31.3-2002, New York, NY, 2002.

[23] Swedish Nuclear Power Companies, TBM: Technical Requirements for Mechanical Equipment, Revision 6, Stockholm, Sweden, 2012.[13]

[24] Economou, J., Thebault, Y. and Costes, P-E., "Small-Bore Branch Connection Fatigue," PVP2011-57983, Proc. ASME 2011 Pressure Vessels and Piping Division Conference, American Society of Mechanical Engineers, New York, NY, 2011.

[25] Direction Générale de la Sûreté Nucléaire et de la Radioprotection, Assemblages "Socket Welding" du Circuit Primaire Principal des REP, Décision DGSNR-BCCN/OT/VF No. 020406, Paris, France, October 10, 2002.

[26] AFCN, Design and Construction Rules for Mechanical Components of the PWR Nuclear Islands, RRC-M, Paris La Defense, France, 2012.

[27] U.S. Nuclear Regulatory Commission, Generic Aging Lessons Learned (GALL) Report, NUREG-1801, Revision 2, Washington, DC, December 2010.

[28] Doctor, S.R et al, The Technical Basis Supporting ASME Code, Section XI, Appendix VIII: Performance Demonstration for Ultrasonic Examination, NUREG/CR-7165, U.S. Nuclear Regulatory Commission, Washington, DC, May 2013.

[29] Electric Power Research Institute, Materials Reliability Program: Management of Thermal Fatigue in Normally Stagnant Non-Isolable Reactor Coolant System Branch Lines (MRP-146, Revision 1), Report ID 1022564, Palo Alto, CA, June 2011.

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[12] Available at www.antinternational.com.

[13] Available at http://corporate.vattenfall.se/om-oss/var-verksamhet/var-elproduktion/forsmark/entreprenor-och-konsult/pakt/

# APPENDIX A

# CODAP PRG ACTIVITY REPORT

## A.1 PRG Meetings

During the 3-½ years (2011-2014) of the First Term of the CODAP Project, the Project Review Group met on eight (8) occasions (Table A-1). With the exception for CODAP02 and CODAP08, all meetings were held at the OECD Conference Centre, Paris, France. The CODAP02 and CODAP08 meetings were held at NEA Headquarters in Issy-les-Moulineaux, France.

**Table A-1: Project Review Group Meetings 2011-2014**

| Meeting | Date(s) |
|---|---|
| CODAP01, Project Kick-off Meeting | May 18-19, 2011 |
| CODAP02, National Coordinators Meeting | November 8-9, 2011 |
| CODAP03, National Coordinators Meeting | May 29-30, 2012 |
| CODAP04, National Coordinators Meeting | December 11-12, 2012 |
| CODAO05, National Coordinators Meeting | May 30-31, 2013 |
| CODAP06, National Coordinators Meeting | November 6-7, 2013 |
| CODAP07, National Coordinators Meeting | May 14-15, 2014 |
| CODAP08, National Coordinators Meeting | December 9-10, 2014 |
| CODAP Phase 2 Kick-off Meeting | December 11, 2014 |

## A.2 CODAP Topical Reports

During the First Term of CODAP the PRG produced two Topical Reports. These reports constitute CODAP Event Database and Knowledge Base insights reports and are intended as “portals” for future database application projects and in-depth studies of selected degradation mechanisms. Prepared in 2013, a first Topical Report addressed flow-accelerated corrosion (FAC) of carbon steel and low alloy steel piping (NEA/CSNI/R(2014)6). A second Topical Report addressed operating experience with electro-hydraulic control (EHC) and instrument air (IA) system piping (NEA/CSNI/R(2015)6). Both reports are in the public domain and available as PDFs on the Internet at http://www.oecd-nea.org/nsd/docs/indexcsni.html.

## A.3 CSNI WGRISK Project on “Use of OECD Data Project Products in PSA”

During 2012 the PRG supported the subject Working Group on Risk (WGRISK) project by attending meetings, sharing of information and responding to a survey on database applications in the context of PSA. On October 15-16, 2012, the PRG presented its perspectives on the use of the OPDE/CODAP data project products in PSA. The results of the survey on database applications are documented in NEA/CSNI/R(2014)2: Use of OECD/NEA Data Project Products in Probabilistic Safety Assessment (June 2014).

## A.4 Conference Participation

During the first term of CODAP, the project was represented at the following international conferences:

- ICONE-20, 20th International Conference on Nuclear Engineering, Anaheim, CA, USA, July 30 – August 3, 2012. On July 30, 2012, project team members delivered a tutorial on “Analytical Framework for the Derivation of Piping Reliability Parameters from Service Experience Data.”

- American Nuclear Society, International Topical Meeting on Probabilistic Safety Assessment and Analysis, Columbia, SC, September 22-26, 2013.

Paper #84, OECD/NEA CODAP Event Data Project on Passive Component Degradation & Failures in Commercial Nuclear Power Plants

- Pacific Basin Nuclear Conference, Vancouver, BC, Canada, August 25-28, 2014.

  Paper PBNC2014-025, OECD/NEA Multilateral Cooperation in the Area of Structural Integrity & Aging Management

- Fontevraud 8, International Conference on the Contribution of Materials Investigations and Operating Experience to LWR's Safety, Performance and Reliability, Avignon, France, September 15-18, 2014.

  Paper O-T05-163, OECD/NEA Component Operational Experience, Degradation & Ageing Project

- 2014 International Mechanical Engineering Congress & Exposition IMECE-2014, Montreal, QC, Canada, November 14-20, 2014.

  Paper IMECE2014-40106 (Plenary Presentation), CODAP Project on International Cooperation in the Area of Structural Integrity of NPP

# APPENDIX B

# GLOSSARY OF TECHNICAL TERMS

*Boat Sample*. The Boat Sampling Technique (BST) has been developed for obtaining samples from the surface of a pressure boundary component. The technique is a nondestructive surface sampling technique as it does not cause any plastic deformation or thermal degradation of the operating component. BST can be used, remotely and in water-submerged condition, with the help of a handling mechanism. The samples are boat-shaped, having 3 mm maximum thickness and require 180 minutes for getting scooped from a location. The samples are used for metallurgical analysis to confirm the integrity of the component. BST incorporates mainly sampling module, handling mechanism and electric and pneumatic sub-systems.

*Bonna Pipe*. Piping intended for raw water service. It is fabricated from rolled and seam welded steel plates. It has an internal concrete liner and an external reinforced concrete liner.

*Cavitation*. Cavitation damage may occur when there is a flowing liquid stream that experiences a drop in pressure followed by a pressure recovery. Such a pressure drop (i.e., the difference between the upstream pressure and the downstream pressure) can occur in valve internals where the flow has to accelerate through a small area. As the fluid moves through the restricted area, the fluid velocity increases and the pressure decreases as shown by the momentum equation (i.e., Bernoulli's theorem). If the local pressure passes below the vapour pressure at the liquid temperature, then small bubbles are formed. When the downstream pressure rises above the vapour pressure, these bubbles collapse. The collapse of the bubbles causes high local pressures and very high local water jet velocities. If the collapsing bubbles are close enough to a solid surface, damage to that surface will occur. The collapse of the numerous bubbles generates noise and vibration. Most often, cavitation causes most of its damage by vibration (e.g., cracked welds, broken instrument lines, loosened flanges). The erosion caused by cavitation also generates particles that contaminate the process fluid.

*Component Boundary*. Defines the physical boundary of a component required for system operation. A component boundary definition should be consistent with the parameter database supporting PSA model quantification. Isometric drawings (fabrication isometrics and ISI isometrics) uniquely defines the piping component boundaries.

*Damage Mechanism*. Excessive internal or external loading conditions that cause physical damage to a component pressure boundary. Examples include, high-cycle vibration fatigue and thermal stratification, as well as pressure shocks from steam/water hammer.

*Degradation Mechanism*. Phenomena or processes that attack (crack, erode, wear, etc) a pressure-retaining material over time and might result in a reduction of pressure boundary integrity. Also, includes phenomena that cause changes in material properties (e.g., reduction in fracture toughness).

*Erosion Cavitation (E-C)*. This phenomenon occurs downstream of a directional change or in the presence of an eddy. Evidence can be seen by round pits in the base metal and is often wrongly diagnosed as FAC (see below). Like erosion, E-C involves fluids accelerating over the surface of a material; however, unlike erosion, the actual fluid is not doing the damage. Rather, cavitation results from small bubbles in a liquid striking a surface. Such bubbles form when the pressure of a fluid drops below the vapour pressure, the pressure at which a liquid becomes a gas. When these bubbles strike the surface, they collapse, or implode. Although a single bubble imploding does not carry much force, over time, the small damage caused by each bubble accumulates. The repeated impact of these implosions results in the formation of pits. Also, like erosion, the presence of chemical corrosion enhances the damage and rate of material removal. E-C has been observed in PWR stainless steel decay heat removal and charging system piping.

*Erosion/Corrosion (E/C)*. "Erosion" is the destruction of metals by the abrasive action of moving fluids, usually accelerated by the presence of solid particles or matter in suspension. When corrosion occurs simultaneously, the term erosion-corrosion is used. In the CODAP Event Database, the term "erosion/corrosion" applies only to moderate energy carbon steel piping (e.g., raw water piping).

*Fatigue.* "Fatigue" refers to an aging degradation mechanism where components undergo cyclic stress. This mechanism involves either low-load, high frequency stresses or high-load, low frequency stresses generated by thermal cycling, vibration, seismic events, or loading transients. Environmental factors may accelerate fatigue and eventually may result in a component failure.

*Fillet Weld*. Fillet welding refers to the process of joining two pieces of metal together whether they be perpendicular or at an angle. The weld is triangular in shape and may have a concave, flat or convex surface depending on the welder's technique

*Flashing*. Flashing occurs when a high-pressure liquid flows through a valve or an orifice to a region of greatly reduced pressure. If the pressure drops below the vapour pressure, some of the liquid will be spontaneously converted to steam. The downstream velocity will be greatly increased due to a much lower average density of the two-phase mixture. The impact of the high velocity liquid on piping or components creates flashing damage.

*Flow Accelerated (or Assisted) Corrosion (FAC)*. FAC is "a process whereby the normally protective oxide layer on carbon or low-alloy steel dissolves into a stream of flowing water or water-steam mixture." It can occur in both single phase and two phase regions. The cause of FAC is a specific set of water chemistry conditions (e.g., pH, level of dissolved oxygen), and there is no mechanical contribution to the dissolution of the normally protective iron oxide (magnetite) layer on the inside pipe wall.

*Liquid Droplet Impingement (LDI)*. Liquid droplet impingement is caused by the impact of high velocity droplets or liquid jets. Normally, LDI occurs when a two-phase stream experiences a high-pressure drop (e.g., across an orifice on a line to the condenser). When this occurs, there is an acceleration of both phases with the liquid velocity increasing to the point that, if the liquid strikes a metallic surface, damage to the surface will occur. The main distinction between flashing and LDI is that in flashing the fluid is of lower quality (mostly liquid with some steam), and with LDI, the fluid is of higher quality (mostly steam with some liquid).

*Repair Weld (or Welding)*. Any welding performed after original construction, but prior to commissioning (e.g., hot functional testing).

*Solid Particle Erosion (SPE).* SPE is damage caused by particles transported by the fluid stream rather than by liquid water or collapsing bubbles. If hard, large particles are present at sufficiently high velocities, damage will occur. In contrast to LDI, the necessary velocities for SPE are quite low. Surfaces damaged by SPE have a very variable morphology. Manifestations of SPE in service usually include thinning of components, a macroscopic scooping appearance following the gas/particle flow field, surface roughening (ranging from polishing to severe roughening, depending on particle size and velocity), lack of the directional grooving characteristics of abrasion, and in some but not all cases, the formation of ripple patterns on metals.

*Thermal Aging*. Possible effects of elevated temperature service include phase transformations that can adversely affect mechanical properties. Extended time at elevated temperature may permit even very slow phase transformations to occur. This is of particular concern for cast stainless steel components where the formation of a brittle alpha-phase can result in a loss of fracture toughness and lead to brittle failure.

*Thermal Stratification*. Hot water can flow above cold water in horizontal runs of piping when the flow (hot water into a cold pipe or cold water into a hot pipe) does not have enough velocity to flush the fluid in the pipe. The temperature profiles in the pipe where the top of the pipe is hotter than the bottom causes the pipe to bow along with the normal expansion at the average temperature.

*Water Hammer*. If the velocity of water or other liquid flowing in a pipe is suddenly reduced, a pressure wave results, which travels up and down the pipe system at the speed of sound in the liquid. Water hammer occurs in systems that are subject to rapid changes in fluid flow rate, including systems with rapidly actuated valves, fast-starting pumps, and check valves.