

# **O**perating Experience Insights into Pipe Failures for Electro- Hydraulic Control and Instrument Air Systems in Nuclear Power Plants

**A Topical Report from the  
Component Operational Experience,  
Degradation and Ageing Programme**

**Unclassified**

**NEA/CSNI/R(2015)6**

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

**26-Mar-2015**

**English text only**

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

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and Instrument Air Systems in Nuclear Power Plant**

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**JT03373218**

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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.

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## **THE COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS**

The NEA Committee on the Safety of Nuclear Installations (CSNI) is an international committee made of senior scientists and engineers, with broad responsibilities for safety technology and research programmes, as well as 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 NEA member countries. The CSNI's main tasks 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; and to promote the co-ordination of work that serves to maintain competence in nuclear safety matters, including the establishment of joint undertakings.

The clear 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 programme of the Agency concerning the regulation, licensing and inspection of nuclear installations with regard to safety. It also co-operates with the other NEA's Standing Committees as well as with key international organisations (e.g. the 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 for example 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 and 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 OECD/NEA Committee on the Safety of Nuclear Installations (CSNI) acts as an umbrella committee of the Project.

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 Stress Corrosion Cracking and Cable Ageing Project” (SCAP). OPDE was formally launched in May 2002. Upon completion of the third 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. The majority of the member organisations of the two projects were the same, often being represented by the same person. In May 2011, thirteen countries signed the CODAP 1<sup>st</sup> Term Agreement (Canada, Chinese Taipei, Czech Republic, Finland, France, Germany, Japan, Korea (Republic of), Slovak Republic, Spain, Sweden, Switzerland and the United States). The 1<sup>st</sup> Term work plan includes the preparation of Topical Reports to foster technical co-operation and to deepen the understanding of national differences in ageing management.

The Topical Reports constitute CODAP Event Database and Knowledge Base insights reports and as such act as portals for future database application projects and in-depth studies of selected degradation mechanisms. Prepared in 2013 and published as NEA/CSNI/R(2014)6, a first Topical Report addressed flow accelerated corrosion (FAC) of carbon steel and low alloy steel piping. This, the second Topical Report addresses operating experience with electro-hydraulic control (EHC) and instrument air (IA) system piping.

Degradation and failure of EHC or IA piping can adversely affect plant operability, and under certain circumstances lead to safety challenges. Both systems consist of significant lengths of small-diameter piping. The typical EHC system piping material is stainless steel; Type 304 or 316. Plants generally use carbon steel, copper, stainless steel, galvanised steel or combinations of two or more material types for IA system piping. The CODAP Topical Report on “EHC and IA Piping Systems” includes a primer on the environmental and operational factors affecting the structural integrity of respective system, and evaluates service experience data as recorded in the CODAP Event Database. Also included in the report are descriptions of the national EHC and IA ageing management programme approaches and a summary of other information collected in the CODAP Knowledge Base. The report has been prepared by the CODAP

Project Review Group, with support from the CODAP Operating Agent and the CODAP Knowledge Base Co-ordinator.

There are 215 records on EHC and IA pipe failures in the CODAP Event Database. Over 90% of the recorded EHC pipe failures and almost 50% of the recorded IA pipe failure events have resulted in manual or automatic reactor trip. A pipe failure in EHC and IA piping often results in a reactor trip, therefore, the following actions are recommended for avoiding the trips caused by small diameter piping:

- Critical parts of small diameter piping should be included into the preventive maintenance program of plant.
- Tolerance of shutdown systems against faults of their supporting EHC and IC systems should be analysed and number of redundant components should be increased, if necessary.

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**LIST OF ABBREVIATIONS AND ACRONYMS**

AMP	Ageing Management Programme
CCI	Common Cause Initiating Event
CCW	Component Cooling Water
CODAP	Component Operational Experience, Degradation and Ageing Programme
EHC	Electro-Hydraulic Control
ESF	Engineered Safeguards Feature
GALL	Generic Ageing Lessons Learned
HF	Human Factor
IA	Instrument Air
KB	Knowledge Base
LCO	Limiting Condition for Operation
MTCS	Main Turbine Control System
NEA	Nuclear Energy Agency
NDE	Non-Destructive Examination
NRC	Nuclear Regulatory Commission
OECD	Organisation for Economic Cooperation and Development
OPDE	OECD Pipe Failure Data Exchange
PSA	Probabilistic Safety Assessment
RC	Reactor Coolant
RPS	Reactor Protection System
RV	Relief Valve
SCAP	Stress Corrosion Cracking and Cable Ageing Project
SCC	Stress Corrosion Cracking
SSC	Structure System and Component



## 1. INTRODUCTION

This, the second CODAP Topical Report addresses operating experience insights on two types of piping systems that have the following features in common: 1) the two systems consist of small-diameter piping, and 2) a pipe failure anywhere in either of the piping systems can have immediate operational impact such as an automatic reactor trip. The electro-hydraulic control (EHC)<sup>1</sup> and instrument air (IA) systems consist of significant lengths of small-diameter piping. The EHC system is vital for power generation. The IA system is an important support system for various plant safety functions. This Topical Report on EHC and IA piping reliability is an information resource developed by the CODAP Project Review Group. The report summarises an evaluation of the EHC- and IA-specific piping service experience data included in the CODAP Event Database and information from the CODAP Knowledge Base.

### 1.1 Technical Scope of CODAP Topical Report No. 2

This CODAP Topical Report addresses EHC and IA piping systems and their susceptibilities to damage or degradation mechanisms. A failure (minor through-wall flaw to full break) of EHC piping can cause plant transients and consequential manual or automatic reactor trip. A failure of IA piping can result in a common cause initiating (CCI) event. In addition to requiring reactor shutdown, a CCI could simultaneously disable one or more of the mitigating systems required to control the plant status following the shutdown. The available service experience data shows that a break in a small-diameter pipe can have a significant impact on plant operations. The report summarises basic EHC and IA piping design information and insights from the review of service experience data as included in the CODAP Event Database. The IA system is an important support system for various plant safety functions.

### 1.2 Safety Significance of EHC and IA Pipe Failures

The EHC system is a non-safety-related system whose failure can cause a reactor trip or actuation of a safety system. Turbine trip and reactor trip following an EHC pipe break are not uncommon occurrences. Plant-specific probabilistic safety assessment (PSA) models do not usually include an explicit consideration of EHC component failures, however.

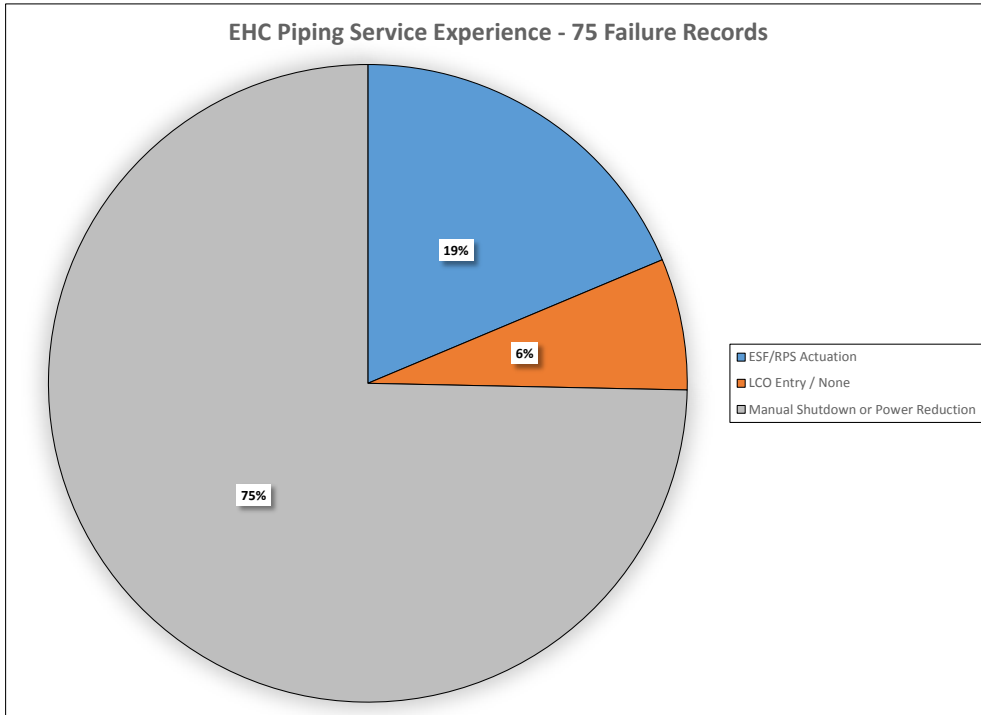
The IA system is an important support system. Loss of IA due to a pipe break could lead to immediate reactor trip. Plant-specific PSA models include detailed consideration of support system initiating events such as loss of IA [1]. The US Nuclear Regulatory Commission (NRC) has issued Generic Letter 88-14 [2] and Information Notices 81-38 [3], 87-28 [4] and 2008-06 [5] to address problems and effects of IA system failures.

The observed impact of EHC and IA pipe failure on plant operation is illustrated in Figures 1 and 2, respectively. In the CODAP Event Database the EHC pipe failure population consists of 75 records, 80% of which are US data. Over 90% of the recorded EHC pipe failures have resulted in either automatic or manual reactor trip. The IA pipe failure event population consists of 140 records, 70% of which are US data. Less than 10% of the recorded IA pipe failures have had no direct impact on plant operation.

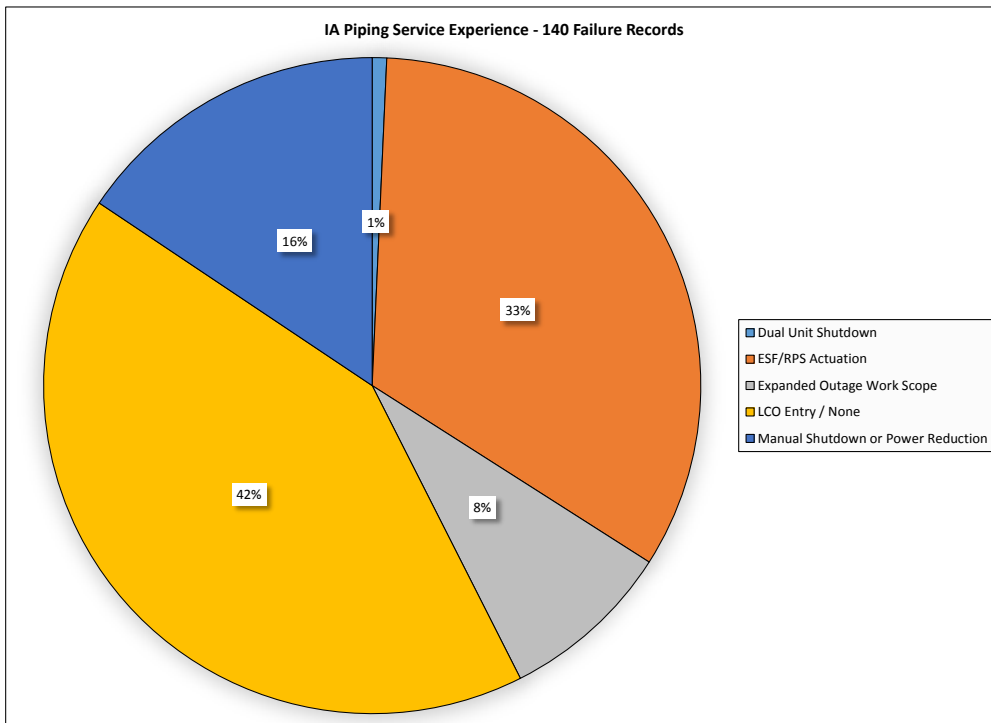
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1. The EHC system is also referred to as Main Turbine Control System (MTCS).

**Figure 1: Observed Impact of EHC Pipe Failure on Plant Operation**



**Figure 2: Observed Impact of IA Pipe Failure on Plant Operation**



### **1.3 Report Structure**

This report is structured as follows: Section 2 describes the CODAP Event Database and Knowledge Base. Section 3 includes EHC and IA system descriptions. Section 4 summarises the CODAP EHC and IA pipe failure event content. Section 5 includes a summary and conclusions. A list of references is included in Section 6. Appendix A 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 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 3<sup>rd</sup> 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 as well as a Knowledge base as in SCAP but with the full range of failure mechanisms as in OPDE.

### 2.1 Project History

The preparation for the OECD Pipe Failure Data Exchange (OPDE) Project was initiated in 1994 by the Swedish Nuclear Power Inspectorate (SKI)<sup>2</sup>. In 1994 SKI launched a 5-year R&D project to explore the viability of creating an international pipe failure database and a related analytical basis for deriving reliability parameters for use in PSA. During this period SKI hosted meetings to present results of the R&D and to discuss the principles of database development and maintenance.<sup>3</sup> In September 2000 and, again in April 2001, the OECD/NEA organised preparatory meetings to explore the feasibility and interest in forming an international cooperative effort to systematically collect, evaluate and exchange service experience data.

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 starting point for the Project was an in-kind contribution by SKI in the form of an international pipe failure database in Microsoft<sup>®</sup> Access. This database included pipe failure data for the period 1970 to 1998, and it contained approximately 2,300 records. During the first term of OPDE the emphasis was on validating the content of the SKI in-kind contribution, improving and streamlining the database structure and data input format, and populating the database with new failure data for the period 1999 to the present, as well as with pre-1998 records. The data validation benefitted from multi-disciplinary considerations, including material science, structural integrity and PSA. The first term of the Project covered the years 2002-2005, the second term covered the period 2005-2008 [6], and the final term covered the period 2008-2011 [7].

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

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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 organised the “Seminar on Piping Reliability” (SKI Report 97:32); this time with participants from eleven countries. SKI Report 97:32 is available on the Internet at [www.ssm.se](http://www.ssm.se).



management, two subjects: stress corrosion cracking (SCC) and degradation of cable insulation. The project ran successfully from June 2006 to June 2010 [8].

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 are 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. It is intended that CODAP will also include information on age-related degradation of buried tanks and plastic piping.

In May 2011 the Project Review Group (PRG) approved the transition of OPDE to a new, expanded “OECD-NEA Component Operational Experience, Degradation and Ageing Program (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 (eleven member countries), 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.

During the three OPDE Project Terms (2002-2011), the event database was maintained and distributed as a Microsoft<sup>®</sup> Access database. This database was distributed on a CD to the National Coordinators twice per annum. 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 management (e.g. reviews, edits, QA, queries, validation) as well as downloading selected event records or the entire database to a local computer or computer network. The event database structure also includes a provision for uploading of event-specific information such as photographs, isometric drawings and root cause analysis reports. 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 ageing management programmes. As is the case for the event database, the KB also resides on a secure server at NEA Headquarters.

## 2.2 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:

- 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;

- Through-wall defects without active leakage (leakage may be detected following a plant operational mode change involving depressurisation 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 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. 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 mix of free-format fields for detailed narrative information and fields defined by drop-down menus with key words (or data filters) or related tables. 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, structural integrity and PSA.

### 2.3 CODAP Knowledge Base

The CODAP Knowledge Base 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 degradation mechanisms. The KB is intended to provide a source of systematically organised information for members, as well as input to the topical reports the project is intending to prepare. 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: to upload files for inclusion in the common KB and to

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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 common folders all documents are in English.

### **3. ELECTRO-HYDRAULIC CONTROL AND INSTRUMENT AIR SYSTEM DESCRIPTION**

Failure of the piping of electro-hydraulic control (EHC) and instrument air (IA) system has resulted in common cause initiating events, plant load reduction and plant trips. This section contains short descriptions of the main EHC and IA system design features, including piping material selections.

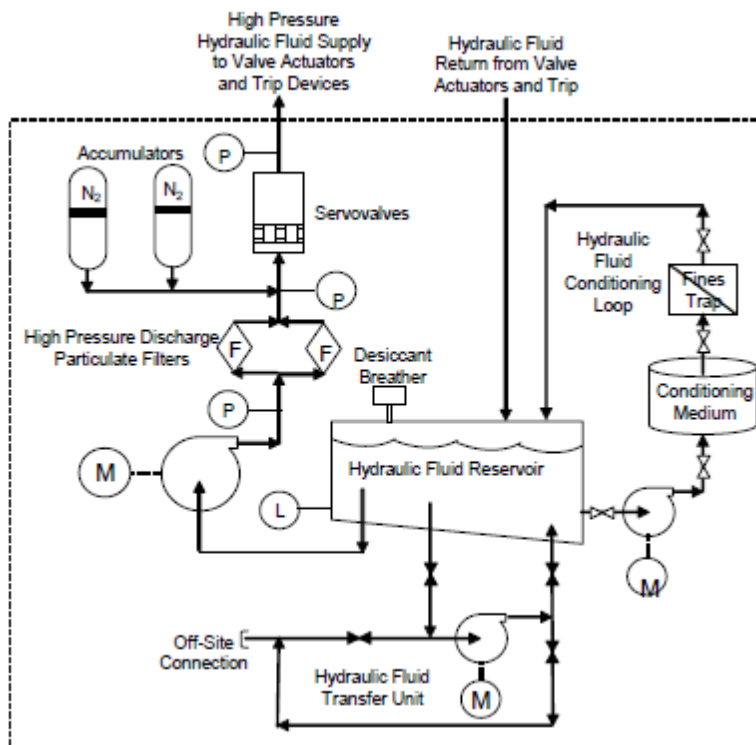
#### **3.1 Electro-Hydraulic Control System**

Overviews of EHC system design, maintenance and operating experience insights are documented in References [9][10][11]. The electro-hydraulic control (EHC) system supplies high-pressure fire resistant hydraulic fluid to the main turbine instrumentation and control system to serve as the primary hydraulic medium for operating the main turbine control valves, stop valves, and intercept valves. Figure 3 shows the hydraulic portion of a typical EHC system. Hence, the main function of the EHC system is to regulate turbine speed, maintain set load, control rate of load increases, and provide protection for the turbine and generator. For BWR plants, an additional function is to control reactor pressure. EHC system pressure is maintained by positive displacement pumps and, depending on the particular system design and mode of operation, the system operates at a pressure range of 7 to 15 MPa. The major equipment of the EHC system is supplied with the main turbine-generator package and it consists of the following five major parts:

1. Electrical/electronic controls portion
2. Hydraulic fluid system – the subject of this Topical Report
3. Emergency trip system
4. Valve controllers
5. Trip and monitoring system

The EHC system equipment may be required to function during any one of a number of normal and emergency plant operating modes. The EHC system is generally not considered a safety-related system but it is vital for power generation. A failure of the EHC system can result in turbine/reactor trip or the reactor unit being prevented from starting up. A main turbine over-speed condition could cause turbine blade and/or rotor failure and generate missile hazards that could damage nearby safety related systems. The turbine manufacturers use triaryl phosphate esters as the circulating fluid. These phosphate esters provide improved fire resistance over hydrocarbon-based fluids, and thereby minimise the risk for a fire due to a high pressure EHC line leaking onto a hot surface or other ignition source.

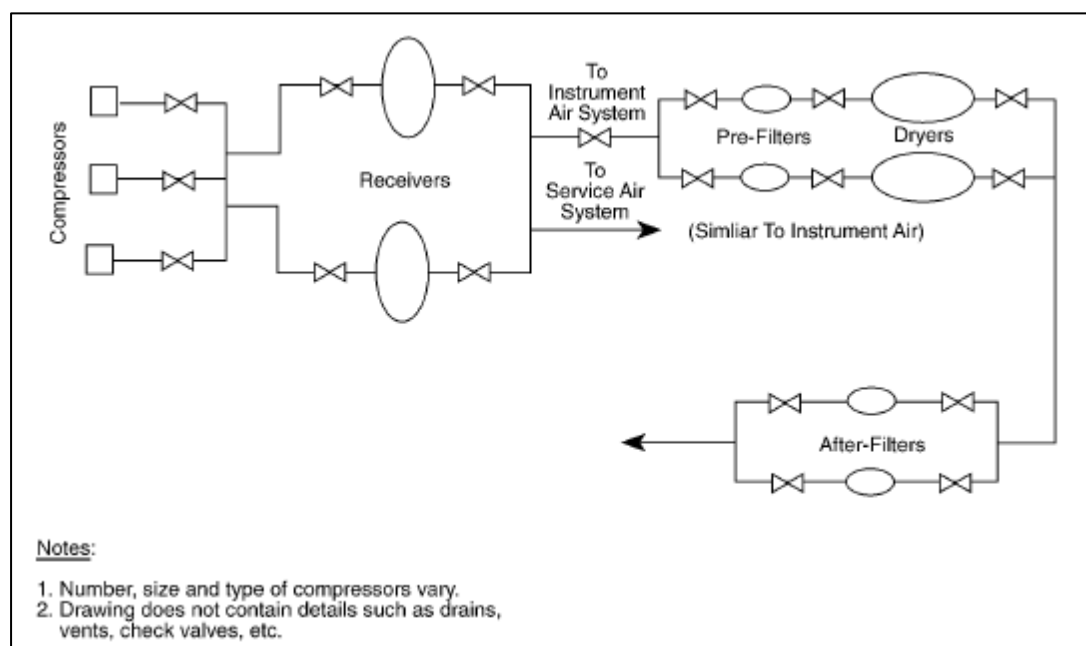
The EHC fluid system consists of numerous runs of small-diameter hydraulic piping and tubing to convey the EHC hydraulic fluid to the valve actuators where it is needed. The tubing, fitting, and piping material used in EHC systems is typically type 304 stainless steel for the tubing and piping and type 316 stainless steel for the fittings. These materials were selected because of the hydraulic fluid pressure and their suitability for use in high-purity fluid systems.

**Figure 3:** Hydraulic Portion of a Typical EHC System

### 3.2 Instrument Air System

Overviews of EHC system design, maintenance and operating experience insights are documented in References [11][14][15][16][17]. The instrument air (IA) system supplies dry, filtered compressed air for various pneumatic controls, air-operated valve controllers and positioners, and pneumatic instrumentation in a nuclear power plant. It is also the source of compressed air delivered to and stored in safety-related accumulators via safety-related check valves. In turn, the charged accumulators serve as standby sources of pneumatic motive power to operate critical air-operated valves and devices required for safe shutdown of the nuclear station. Accordingly, the specifications for the instrument air system require the supply of dry, filtered, clean, and oil-free air within a specific operating pressure range and below a given maximum design pressure dew point. It is essential to maintain the quality of the compressed air delivered by the IA system to critical plant pneumatic devices. Any moisture, oil, desiccant, particulates, or other contaminants in the system, will degrade the performance of pneumatic devices or cause complete malfunction, which may seriously compromise overall safety of the nuclear plant.

An IA system consists of three subsystems: the compressed air supply train, a filter/dryer train, and a distribution section - which is the focus of this Topical Report. Figure 4 shows a typical IA system layout. The air compressor draws in air from the atmosphere via an intake filter/silencer which removes dirt and other particles and reduces the noise at the compressor intake. The compressor itself is usually powered by an electric motor. Two types of compressors are used: 1) reciprocating, and 2) screw compressor. The compressor discharges to an after-cooler, a water-cooled heat exchanger, which cools the compressed air. Cooling water for the after-cooler and any intercoolers for multi-stage air compressors is usually provided by the plant component cooling water (CCW) system. A moisture separator connected directly to the discharge of the after-cooler removes condensation and oil from the air stream before the air enters the air receivers. The IA systems with reciprocating compressors tend to be more failure prone than those with screw compressors.

**Figure 4:** Example of IA System Layout

The air leaving the moisture separator passes into the air receiver usually via a check valve and an isolation valve. The air receiver acts as a storage tank for the compressed air and dampens out the pulsations and pressure surges generated by the compressor. A pressure relief valve or a safety valve is normally placed at the compressor's discharge to protect the discharge piping and the after-cooler/moisture separator from overpressurisation. A relief valve is also placed at the air receiver to prevent the tank from exceeding its pressure limit. The typical system operating pressure is approximately 0.8 MPa.

In the past, the IA systems were not designed to satisfy the single failure criterion. Therefore, older systems are susceptible to single failure modes such as a pipe break that can cause a loss of IA pressure in a portion of the system, or in the entire system. This is discussed further in the section on IA piping service experience. Safety related components are typically designed to fail in a position least hazardous to the plant, or, if they are required to be operable after IA pressure has decreased, they are provided with accumulators that maintain an air reservoir for subsequent operation. However, operating experience has revealed a number of failure modes for safety related components that were not considered during design. For example, valves with failure modes opposite to that assumed in safety analyses have been installed, air operated valves have not operated as expected due to reversal of the supply and exhaust lines, and valves have not repositioned properly on loss of IA.

The IA distribution section of a compressed air system consists of the headers, piping, air connections stations, and hoses that deliver the compressed air to the pneumatic devices. Two basic distribution configurations are found: 1) radial distribution, and 2) ring header distribution. Very often elements of both methods are combined. The radial distribution approach uses a single, large air header to transport the compressed air into the plant, branching off along the way to radial headers in individual buildings (e.g. Containment, Reactor Building, Turbine Building).

IA system piping materials vary a great deal between nuclear power plants. Plants generally use carbon steel, hard copper, stainless steel, galvanised steel or a combination of two or more of these. Copper piping is in common use at many facilities, but such systems are susceptible to joint failures. In order to strengthen the joints and lessen the possibility of failures, some plants require that copper piping joints be braced instead of soldered; others use stainless steel piping. Plants with “clean dry instrument air” have

opted to replace their copper lines with carbon steel piping with welded joints. The IA pipe sizes range from small- (DN20 to DN25) to medium-diameter (e.g. DN75 to DN100 for header pipes).

### **3.3 Ageing Management Considerations**

In Germany the Nuclear Safety Standards Commission (KTA) is responsible for issuing standards for the operation of commercial nuclear power plants. In-service inspection of EHC and IA systems are covered in KTA 3211.4, “Pressure and Activity Retaining Components of Systems Outside the Primary Circuitry. Part 4: In-service Inspections and Operational Monitoring.” Ageing management considerations relative to the two systems are covered in KTA 1403 “Ageing Management in Nuclear Power Plants.”<sup>4</sup>

In the US the EHC system is not included in the scope of systems reviewed for License Renewal [12]. The EHC system is included in respective plant’s Maintenance Rule Program [13], however. The IA system is included in the scope of systems reviewed for License Renewal [12]. Section XI.M24 (Compressed Air Monitoring) of NUREG-1801 (the “GALL Report) addresses IA-specific ageing management programme (AMP) considerations.

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4. The German standards are available on the Internet at [www.kta-gs.de](http://www.kta-gs.de).

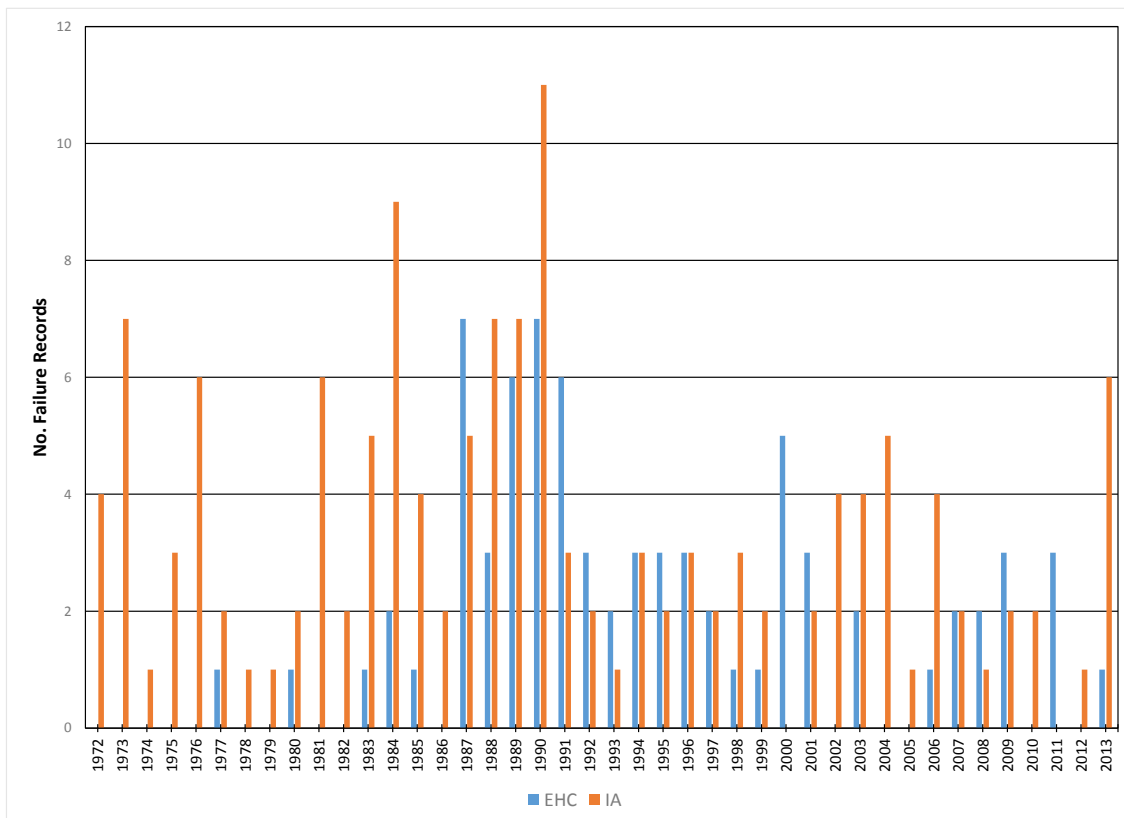
#### 4. EHC AND IA PIPING OPERATING EXPERIENCE INSIGHTS

The EHC and IA piping failure event populations in the CODAP Event Database are summarised in this chapter. The two event populations include non-through wall defects and through-wall defects. The first group represents visual inspection or NDE results where the measured wall thickness is below the minimum wall thickness allowed by the acceptance criteria as formulated in Owner-defined reliability and integrity management programmes.

##### 4.1 High-Level Database Summary

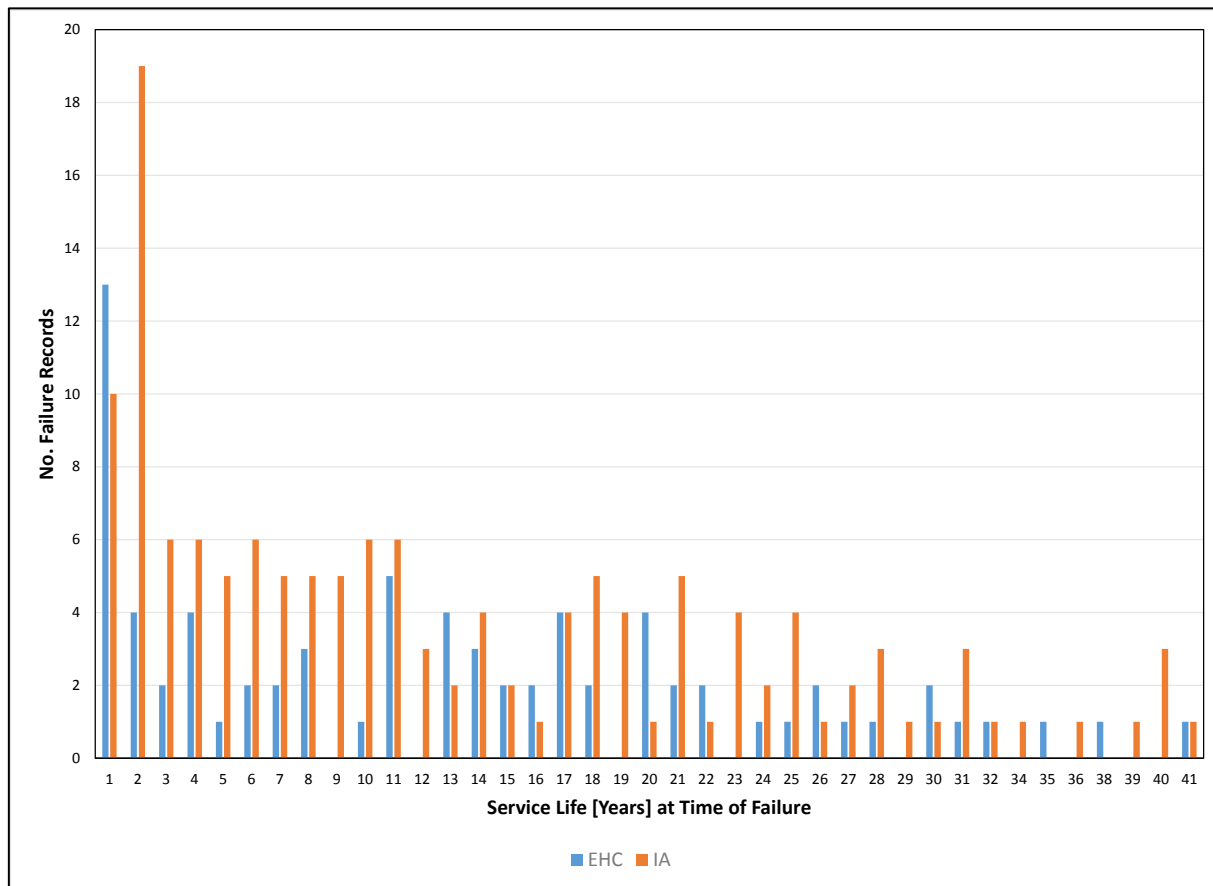
The EHC and IA pipe failure event populations in the CODAP Event Database consist of 75 records and 140 records, respectively (Figures 5 and 6). The recorded events mainly involve pipe failures that have caused immediate plant operational impact such as manual or automatic plant shutdown.

**Figure 5: EHC & IA Pipe Failure Event Populations by Calendar Year**





**Figure 6:** EHC & IA Pipe Failure Data as a Function of Service Life at the Time of Failure



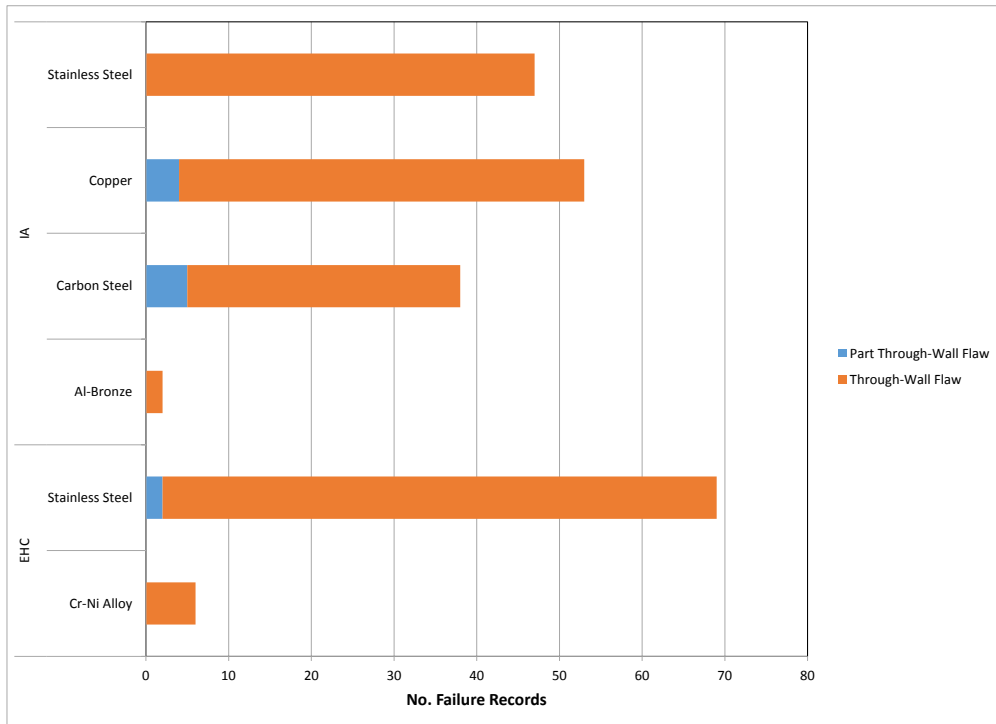
## 4.2 Data Reduction

In this section the EHC and IA pipe failure data is reviewed in more detail by querying the CODAP Event Database on records by failure mode, material type and damage/degradation mechanisms. Figure 7 is a summary of the database content by system and material type. As previously noted, the EHC piping material is stainless steel. There is one exception, however according to the CODAP Event Database, one BWR plant uses a nickel-base alloy for the EHC piping.

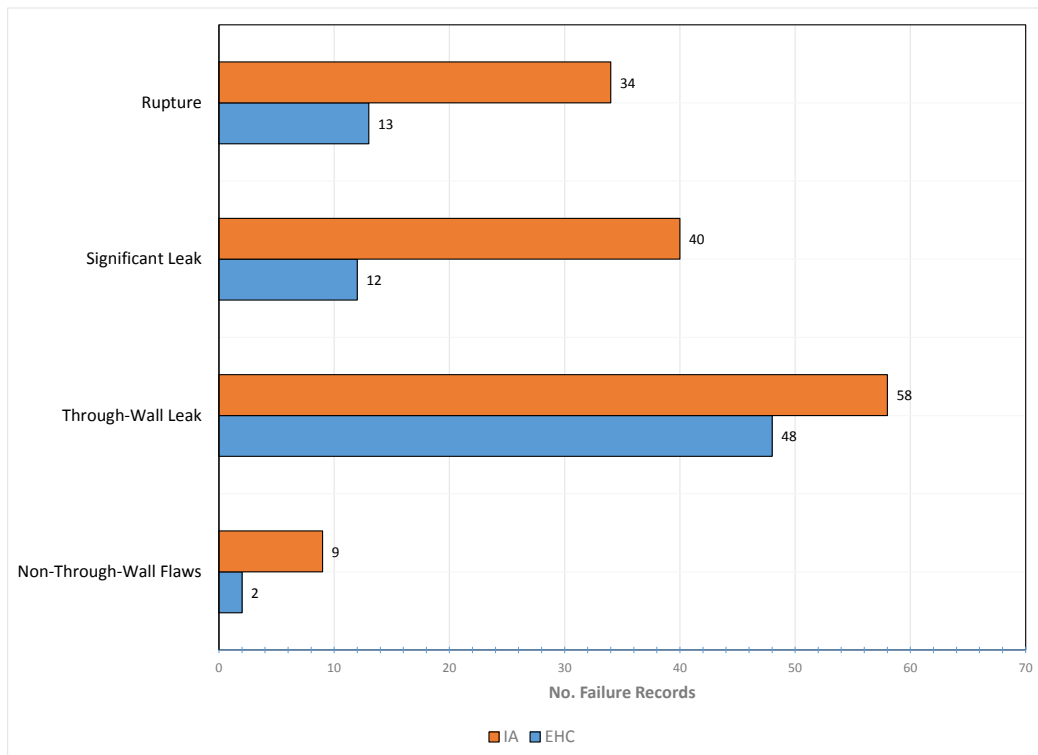
Figure 8 is a summary of the database content by failure mode. Of the total event population (EHC plus IA pipe failures), only 5% of the records are for non-through-wall flaws. This can be explained as follows (Figure 9). A predominant damage mechanism for both systems is high-cycle vibration fatigue. The time for a flaw to propagate through-wall from an initiation site to the pipe outside diameter usually is quite short. This means that non-destructive examination (NDE) would not be effective in preventing failure of the small-diameter piping, and as a result the ratio of recorded non-through-wall to through-wall flaws would be expected to be low.

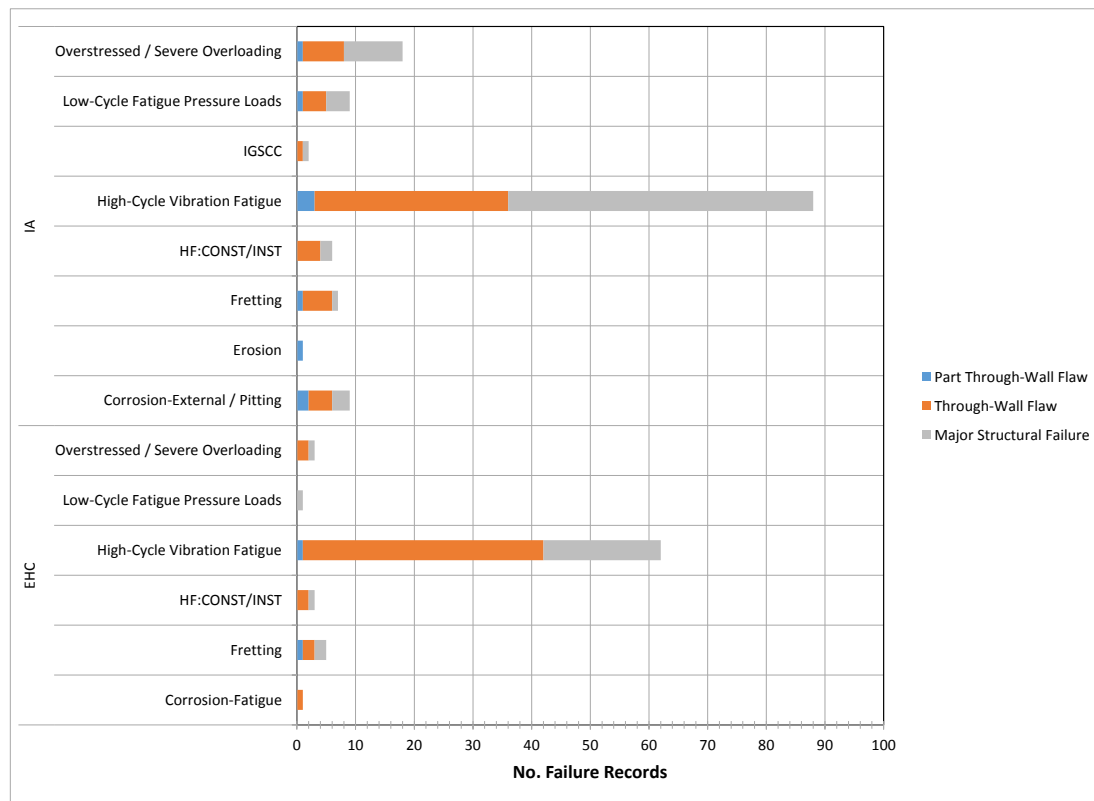
The database includes two (2) failure records involving stress corrosion cracking (SCC) of IA piping. In both cases, the SCC is attributed to attack by ammonia on copper alloy C2300, which is composed of 14-16% zinc, 0.05% iron and lead, and the remainder copper. This material is known to be susceptible to SCC. In one instance, SCC caused a major axial split in a DN50 instrument air supply header. The affected plant was in cold shutdown at the time of the pipe failure. A failure at-power would have resulted in an automatic reactor trip.

**Figure 7: EHC & IA Pipe Failure Data by Material Type**



**Figure 8: EHC & IA Pipe Failure Data by Failure Mode**



**Figure 9: EHC & IA Pipe Failure Data by Damage/Degradation Mechanism**

In Figure 7, the term “Overstressed/Severe Overloading” implies that a small-diameter pipe has failed through external, unexpected loading conditions. A review of the root cause analysis reports point to situations where plant maintenance personnel inadvertently stepped on piping or used the piping as a handle bar. The term “HF:CONST/INST” involves inadequate pipe fit-up or connection of pipe to a valve body.

### 4.3 Noteworthy Events

Examples of noteworthy EHC and IA pipe failure events include the following:

- Plant A (BWR). In September 1991, an EHC Fluid Tank low level alarm activated after all four Main Turbine Control Valves had been cycled for required monthly Reactor Protection Surveillances. An EHC hydraulic oil leak was discovered at the #2 Main Turbine Control Valve. When it became apparent that the leak could not be controlled, a Unit shutdown was initiated. One leak was found at the ½-inch stainless steel tubing which supplies hydraulic fluid at 11 MPa to the #2 Control Valve. The cause of the leak has been attributed to broken and damaged piping supports that allowed the EHC lines to vibrate excessively.
- Plant B (PWR). A reactor trip in June 1990 was attributed to an EHC line rupture. The pipe failed at a support clamp which had been clamped without a rubber or flexible grommet or insulating material, hard against the pipe, and acted as a stress inducing site.
- Plant C (two-unit PWR): In November 1988, a rapid decrease in IA header pressure caused feedwater regulating valves to close at both units, leading to manual trip of both reactors. The

cause of the IA system failure was attributed to failure of a 4-inch copper line solder joint in an IA header pipe shared by both units.

- Plant D (PHWR). In December 1994, a small primary pressure boundary leakage occurred due to a reactor coolant (RC) 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 IA copper 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.



## 5. SUMMARY AND CONCLUSIONS

### 5.1 Summary

Pipe failure events involving small-diameter EHC and IA piping was selected as the subject of the second CODAP Topical Report. Existing service experience data as recorded in the CODAP Event Database demonstrates that a through-wall defect in these piping systems can have a significant impact on plant operations. The EHC system is vital for power operation. The IA system is an important support system for various plant safety functions. The 2014 version of the CODAP Event Database includes 215 records on EHC and IA pipe failures. Over 90% of the recorded EHC pipe failures have resulted in manual or automatic reactor trip. Of the recorded IA pipe failure events, almost 50% resulted in manual or automatic reactor trip.

Recent (2000-2013) operating experience demonstrates that EHC and IA pipe failures continue to cause interruptions of routine plant operation. Steps are taken to improve the routing and support of the small-diameter piping systems to mitigate the susceptibility to vibration fatigue damage.

The CODAP Knowledge Base includes documentation on the national regulatory approaches to ageing management of small-diameter piping such as the EHC and IA piping.

### 5.2 Conclusions

The Topical Report on EHC and IA piping operating experience insights address the different damage and degradation mechanisms that are known to affect the small-diameter piping. The current operating experience points to examples where a relatively benign through-wall defect in small-diameter piping has caused significant plant disturbances. As recorded in the CODAP Event Database, a high-level summary is provided of the international operating experience with EHC and IA piping.

A pipe failure in EHC and IA piping often results in a reactor trip, therefore, the following actions are recommended for avoiding the trips caused by small diameter piping:

- Critical parts of small diameter piping should be included into the preventive maintenance program of plant
- Tolerance of shutdown systems against faults of their supporting EHC and IC systems should be analysed and number of redundant components should be increased, if necessary



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## APPENDIX A

## GLOSSARY OF TECHNICAL TERMS

***Common Cause Initiating Event:*** A unique class of initiating events which, in addition to requiring reactor shutdown, simultaneously disable one or more of the mitigating systems required to control the plant status following the initiator.

***Desiccant:*** A hygroscopic substance which induces or sustains a state of dryness (desiccation) in its vicinity. Commonly encountered pre-packaged desiccants are solids that absorb water. Desiccants for specialised purposes may be in forms other than solid, and may work through other principles, such as chemical bonding of water molecules. Industrially, desiccants are widely used to control the level of water in gas streams.

***Maintenance Rule:*** In 1991 the USNRC published 10 CFR 50.65 (commonly referred to as the “maintenance rule”) which requires that each licensee monitors the performance or condition of SSCs against licensee-established goals in a manner sufficient to provide reasonable assurance that such SSCs are capable of fulfilling their intended functions. Such goals are to be established commensurate with safety and, where practical, take into account industrywide operating experience. When the performance or condition of an SSC does not meet established goals, appropriate corrective action must be taken. For additional details see Regulatory Guide 1.160, Revision 3 (May 2013).<sup>5</sup>

***Triaryl Phosphate Ester:*** A fire resistant self-extinguishing electro-hydraulic control fluid especially developed for steam turbine application. According to the US National Fire Protection Association (NFPA) Recommended Practice 850 (“Fire Protection for Electric Generating Plants”), a fire resistant fluid “...is difficult to ignite and does not sustain combustion due to its low heat of combustion.”

***Valve Chatter:*** Chattering is the rapid opening and closing of a pressure-relief valve. The resulting vibration may cause misalignment, valve seat damage, and, if prolonged, mechanical failure of valve internals and associated piping. Some causes of chattering include: excessive inlet pressure drop; excessive backpressure; an oversized relief valve; and a relief valve that must handle widely varying flow rates.

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5. Available on the Internet at [www.nrc.gov](http://www.nrc.gov).