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NEA CODAP Project Topical Report on Basic Principles of Collecting and Evaluating Operating Experience Data on Metallic Passive Components

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NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

NEA CODAP PROJECT TOPICAL REPORT ON BASIC PRINCIPLES OF COLLECTING AND EVALUATING OPERATING EXPERIENCE DATA ON METALLIC PASSIVE COMPONENTS

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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 sound 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 analyses in areas such as energy and the sustainable development of low-carbon economies.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management and decommissioning, 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.

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

The Committee on the Safety of Nuclear Installations (CSNI) is responsible for the Nuclear Energy Agency (NEA) programmes and activities that support maintaining and advancing the scientific and technical knowledge base of the safety of nuclear installations.

The Committee constitutes a forum for the exchange of technical information and for collaboration between organisations, which can contribute, from their respective backgrounds in research, development and engineering, to its activities. It has regard to the exchange of information between member countries and safety R&D programmes of various sizes in order to keep all member countries involved in and abreast of developments in technical safety matters.

The Committee reviews the state of knowledge on important topics of nuclear safety science and techniques and of safety assessments, and ensures that operating experience is appropriately accounted for in its activities. It initiates and conducts programmes identified by these reviews and assessments in order to confirm safety, overcome discrepancies, develop improvements and reach consensus on technical issues of common interest. It promotes the co-ordination of work in different member countries that serve to maintain and enhance competence in nuclear safety matters, including the establishment of joint undertakings (e.g. joint research and data projects), and assists in the feedback of the results to participating organisations. The Committee ensures that valuable end-products of the technical reviews and analyses are provided to members in a timely manner, and made publicly available when appropriate, to support broader nuclear safety.

The Committee focuses primarily on the safety aspects of existing power reactors, other nuclear installations and new power reactors; it also considers the safety implications of scientific and technical developments of future reactor technologies and designs. Further, the scope for the Committee includes human and organisational research activities and technical developments that affect nuclear safety.

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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. the Nuclear Energy Agency [NEA], the International Atomic Energy Agency [IAEA], the Joint Research Centre [JRC] Operating Experience Clearinghouse) and industry organisations worldwide. This information is often used 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 NEA member countries have agreed to establish the 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 13 members of CODAP in its third term (2018-2020) are as follows: Canada, the Czech Republic, Finland, France, Germany, Korea, Japan, the Netherlands, the Slovak Republic, Spain, Switzerland, Chinese Taipei, and the United States. Sigma-Phase Inc., from the United States, works as the Operating Agent of the CODAP project.

This fifth CODAP topical report focuses on the CODAP event database structure and the underlying principles of collecting operating experience data on metallic passive components. The report represents a summary of the CODAP Operating Procedures, the CODAP Event Database Coding Guideline, and the CODAP Applications Handbook. This report documents the CODAP Event Database structure and the underlying technical considerations to achieve high data quality as well as database comprehensiveness. Specifically, the report responds to the following frequently asked questions:

- How is the quality of the data in the event database controlled and monitored?
- What is the level of database completeness and comprehensiveness?
- What are the guiding principles of how the database is populated with failure event information?
- Does the database support applications (or, what is its fitness-for-use)?

The report describes the methods to add event data, the internal quality review methods of data and gives an overview on the number and nature of events in the database. Providing support for different applications is a continuous target of the CODAP database development. With respect to the continued database development and maintenance (i.e. data submissions and validation) it is recommended that the following actions be considered in the ongoing active data submission activities of the CODAP database project:

- improve the coding navigation tools;
- encourage the PRG Membership to more actively share metallic passive component operating experience insights, to use the collected data for analysis and to share data analysis insights with the nuclear safety community;
- expand the sharing of operating experience data within the PRG. Future Working Group Meetings should include, as a standing item, national overviews of recent operational events, including the findings of root cause analyses.

The CODAP PRG faces two important future challenges:

- Firstly, while efforts have been made to promote CODAP and associated data project products to the nuclear safety community at large, there remain programmatic issues relative to how to make the restricted CODAP event database available to PSA practitioners.
- Secondly, work remains to be done relative to the development of PSA-centric database application guidelines and associated analytical infrastructure (i.e. piping reliability analysis techniques and tools).

Additionally, a proposal has been made for an international benchmark exercise concerning the use of operating experience data to quantify piping reliability parameters for input to a standard problem application, e.g. risk informed operability determination.

List of abbreviations and acronyms

AFNOR	Association Française de Normalisation (French standards association)
AMP	Ageing Management Programme
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing of Materials
AKZ	Anlagenkennzeichnungssystem (Germany)
BOP	Balance-of-plant
BSI	British Standards Institution
BWR	Boiling water reactor
CASS	Cast austenitic stainless steel
CC	Capability category
C-F	Corrosion fatigue
CE-OEF	Clearinghouse on operating experience feedback (European Union)
CNRA	Committee on Nuclear Regulatory Activities (NEA)
CODAP	Component Operational Data and Ageing Programme (NEA)
CRDM	Control rod drive mechanism
CRP	Conditional rupture probability
CSNI	Committee on the Safety of Nuclear Installations (NEA)
CSV	Comma separated values
CUF	Cumulative usage factor
D&C	Design and construction defect
DEGB	Double-ended guillotine breaks
DM	Degradation mechanism
DN	Nominal diameter
DQA	Data quality assurance
E-C	Erosion-cavitation
E/C	Erosion/corrosion
EAC	Environmental assisted cracking
ECCS	Emergency core cooling system
ECSCC	External chloride SCC
EHC	Electro-hydraulic Control
EN	European standard
EPRI	Electric Power Research Institute
ESF	Emergency safety function
ESWS	Essential service water system
FAC	Flow-accelerated corrosion
FAD	Flow-assisted degradation
FIV	Flow-induced vibration
FSWOL	Full structural weld overlay
FW	Field weld
FWC	Feedwater and condensate
GALL	Generic ageing lessons learned

GOST	Gosudarstvennyy Standart (Russian standards association)
GTAV	Gas tungsten arc welding
HAZ	Heat-affected zone
HC	High cycle
HCF	High-cycle fatigue
HPI	High-pressure injection
HWC	Hydrogen water chemistry
IA	Instrument air
IAEA	International Atomic Energy Agency
IAGE	CSNI Working Group on Integrity and Ageing of Components and Structures
IASCC	Irradiation assisted stress corrosion cracking
ICES	INPO Consolidated events database system
ICW	Intake cooling water
ID	Inside diameter
IGSCC	Intergranular SCC
ISI	In-service inspection
JIS	Japan Industrial Standard
JRC	Joint Research Centre (of the European Commission)
KKS	Kernkraft kennzeichnung system (Identification System for NPPs)
KWO	Kernkraftwerk Obrigheim
LC	Low cycle
LCF	Low cycle fatigue
LCO	Limiting condition for operation
LDI	Liquid droplet impingement
LTA	Less than adequate
LWR	Light water reactor
MIC	Microbiologically influenced corrosion
MSIP	Mechanical stress improvement process
NC	National coordinator
NDE	Non-destructive examination
NEA	Nuclear Energy Agency
NEI	Nuclear Energy Institute
NMCA	Noble metal chemical application.
NPP	Nuclear power plant
NPSAG	Nordic PSA Group
NRC	Nuclear Regulatory Commission
NSSS	Nuclear steam supply system
NTW	Non-through-wall
NWC	Normal water chemistry
OD	Outside diameter
OE	Operating experience
OPDE	OECD Pipe failure Data Exchange project
PFM	Probabilistic fracture mechanics
PHWR	Pressurised heavy water reactor
PRG	Project review group
PRIS	Power reactor information system
PSA	Probabilistic safety assessment
PSI	Pre-service inspection
PWR	Pressurised water reactor
PWSCC	Primary water SCC

QA	Quality assurance
R&D	Research and development
RCA	Root cause analysis
RCP	Rapid crack propagation
RCP	Reactor coolant pump
RCPB	Reactor coolant pressure boundary
RCS	Reactor coolant system
RI-ISI	Risk-informed in-service inspection
RIM	Reliability and integrity management
RIS	Radiation induced segregation
RPS	Reactor protection system
RPV	Reactor pressure vessel
RR	Reactor recirculation
SAW	Submerged arc welding
SCAP	Stress Corrosion and Cable Ageing Project (NEA)
SCC	Stress corrosion cracking
SG	Steam generator
SEAS	Slovenské elektrárne AS (Slovak Republic)
SFC	Spent fuel cooling
S/G	Steam generator
SGTR	Steam generator tube rupture
SICC	Strain induced corrosion cracking
SKI	Statens kärnkraftinspektion (now SSM, Sweden)
SLR	Subsequent license renewal
SMAW	Shielded metal arc welding
SQL	Structured query language
SRS	Software requirements specification
SS	Stainless steel
SSM	Swedish Radiation Safety Authority
SSMFS	Strålsäkerhetsmyndighetens föreskrifter (Sweden)
STP	Standard temperature and pressure
SW	Depending on the context, either “Service water” or “Shop weld”
TAE	Thermal ageing embrittlement
TF	Thermal fatigue
TGSCC	Transgranular stress corrosion cracking
TWC	Through-wall crack
TSO	Technical support organisation
TTR	Time-to-repair
UF	Usage factor
UHS	Ultimate heat sink
UNE	Spanish standards association
VGB	Vereinigung der Großkesselbesitzer (Germany)
WGIAGE	Working Group on Integrity and Ageing of Components and Structures (NEA)
WPS	Welding process specification
WWER	Water-water energetic reactor
XML	eXstensible markup language

1. Introduction

Since 2002, the Nuclear Energy Agency (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 one, two and three 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 [1]) 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 [2]. In recognition of the expanded scope, the Project Review Group (PRG) approved the transition of OPDE to a new expanded "Component Operational Experience, Degradation & Ageing Programme" (CODAP). The CODAP 2011-2014 [3] and 2015-2017 work programmes include tasks to prepare Topical Reports [4] [5] to foster technical co-operation and to deepen the understanding of national differences in plant ageing management.

In addition to recognising the intrinsic value of exchanging operating experience data and related root cause analysis results and insights, an important motivation for supporting the international collaboration in 2002 was embedded in the then emerging trend towards implementing risk-informed in-service inspection (RI-ISI) programmes. An area of specific interest at the time was concerned with the technical basis for performing pipe failure probability analysis in support of RI-ISI programme development. The potential synergies between a comprehensive database such as CODAP and the development of statistical passive component reliability models have been explored in multiple database application projects[1]. The fifth CODAP topical report documents the CODAP event database structure and the underlying technical considerations for achievement of data quality, completeness and comprehensiveness, and the principles for how to extract passive component reliability information from the database.

1.1. Data collection methodology

The NEA joint database project CODAP exchanges operating experience data on metallic passive component degradation and failure, including service-induced wall thinning, non-through wall cracking, leaking through-wall cracking, pinhole leaks, leakage, rupture and severance (pipe break caused by external impact). The scope of the data exchange is articulated in the "Terms and Conditions for Project Operation." In summary, 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. Unless detected in time,

1. Appendix B includes an OPDE/CODAP bibliography that identifies selected database applications that have been performed or sponsored by the OPDE/CODAP member organisations.

these defects are potential precursors to more severe passive component degradation.
- Loss of fracture toughness of cast austenitic stainless steel piping. The loss of fracture toughness is attributed to thermal ageing embrittlement (TAE).
- 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 "precursor events" 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 standards, certain passive components are substantially more resistant to damage and degradation than others. As an example, for chemically stabilised austenitic stainless steel pressure boundary components, there are no recorded events involving active, through-wall leakage. By contrast, for unstabilised (or "lean") austenitic stainless steel, multiple events involving through-wall leakage have been recorded, albeit with relatively minor observed/measured 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 passive component failures that are included in the CODAP event database are:

- Event-based failures that are attributed to damage mechanisms and local pipe stresses. Examples include high-cycle fatigue (e.g. acoustic or flow-induced) in combination with inadequate or 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 structured query language (SQL) database consisting of ca. 100 uniquely defined data fields. It is a blend of free-format fields for detailed narrative information and fields that are 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 with database field definitions and data input requirements are defined in a coding guideline, which is central to the project, including database maintenance, data validation, quality control, and database applications.

1.2. Objectives and scope

The CODAP project review group (PRG) and its predecessor, the OECD pipe failure data exchange (OPDE) PRG, have expended considerable resources on the development of the CODAP event database, including the database structure and database computer software. This development has benefitted from a multi-disciplinary approach to establish a consensus framework for how to record and analyse operating experience (OE) data on metallic passive component degradation and failure. Project participants with expertise in metallurgy, corrosion science, non-destructive examination (NDE) technology, nuclear engineering, nuclear regulation, piping design, structural reliability, root cause analysis, and PSA were actively engaged in formulating the event database structure and related database application requirements.

Since its inception in 2002 the CODAP PRG has pursued an outreach effort to inform the nuclear science and nuclear safety communities about its activities including the progress with the development of the event database. This outreach programme has consisted of regional workshops, active conference participation, and support to regional R&D activities.

In response to frequently asked questions about the quality of the data in the event database, the level of database completeness and comprehensiveness, and its fitness for application, the PRG during its 12th working group meeting (October 2016) decided to prepare a Topical Report that provides a detailed description of the database structure and its underlying technical justifications. The specific objectives of this topical report are to:

- Provide a definition of the term "data quality" and the underlying data qualification process.
- Document the technical justifications behind the CODAP database structure.
- Describe the database structure in terms of its field definitions and associated "controlling" parameters. That is, the passive component reliability attributes and influence factors that are translated into uniquely defined key words.
- Describe the event database user interface and facilities for interrogating the database.
- Describe data completeness and the role and responsibility of respective PRG Member to ensure an equitable data exchange.
- Describe how the event database can support applications.

The CODAP Project places emphasis on data quality, including the completeness and comprehensiveness of recorded events. Data quality is achieved through a formal validation process as articulated in a coding guideline. The roles and responsibilities with respect to data submissions and data validation are defined in the CODAP operating procedures. This topical report is concerned with the data qualification process as implemented by the CODAP PRG. The CODAP PRG is fully aware of the fact that the full root cause analysis documentation as prepared by an owner/operator or its subject matter experts is not normally disseminated outside the industry and national regulators. The CODAP Coding Guideline includes instructions for what "root cause information" to include in the database. As a guiding principle, the instructions that are provided state that any relevant information on a cause-consequence relationship is to be included. Respective national co-ordinator assumes responsibility for the accuracy of the technical information that is input to the event database. Furthermore, the web-based database has provisions for uploading any available supporting information; e.g. laboratory reports, root cause analysis reports, isometric drawings and photographs.

1.3. Nomenclature

Data quality is a perception or an assessment of a certain data set's fitness to serve its purpose in a given context [6] [7][2] Aspects of data quality include:

- Accuracy.
- Completeness; i.e. ensuring that a given event population captures all relevant OE, and that the process of collecting and evaluating OE data is in compliance with a well-documented set of definitions.
- Update and validation status.
- Relevance with respect to the CODAP work scope definition.
- Relevance with respect to current ageing management processes.
- Consistency across the full set of data records so that any given database query captures all relevant data.
- Robustness with respect to data classification.
- Accessibility for users.

Acceptable data quality is crucial to all aspects of the CODAP project infrastructure. Data quality is affected by the way data is entered, stored and managed. Data quality assurance (DQA) is the process of verifying the accuracy and robustness of data. Maintaining data quality requires going through the data periodically and "scrubbing" it. Typically this involves updating it, standardising it, and de-duplicating records to create a single view of a specific data record. In CODAP "scrubbing" is done through the implementation of a broad range of database queries. Query results provide a means for ensuring that all relevant event records are being extracted from the database in response to the data filters that are being invoked through a query command.

1.4. Report structure and reading guide

This topical report consists of eight sections and three appendices. Section 2 documents the CODAP data quality assurance (DQA) program. Section 3 includes a primer on metallic passive component degradation and failures as an introduction to the technical justifications for the CODAP event database structure. Section 2 details the database structure and data input requirements. A summary of the database application facilities can be found in Section 5. Future database enhancement plans are documented in Section 6. The report summary and recommendations are documented in Section 7. Finally, a list of references is provided in Section 8.

Appendix A includes a listing of all database field definitions and supporting technical information. Appendix B is an OPDE/CODAP bibliography including references to database applications performed or sponsored by OPDE/CODAP member organisations since 2002. Appendix C includes a glossary of terms.

2. For additional perspectives on data quality refer to a white paper entitled "The Six Primary Dimensions for Data Quality Assessment" (2013) available from www.dqglobal.com.

2. Data quality assurance

The usefulness of any component failure data collection depends on the way by which a stated purpose is translated into database design specifications and requirements for data input and validation, access rules, support and maintenance, and quality assurance (QA). The objective of the CODAP quality assurance programme (QAP) is to establish organisational and technical principles and measures for quality assurance (QA) and monitoring of the work during the operation of the CODAP Project to ensure high quality of its products (CODAP event database and topical reports). The QAP applies to all activities in the project and is to be followed by all project participants.

2.1. Principle 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 a 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 properties, water chemistry, temperature, pressure).

For an event to be considered for inclusion in the event database it must undergo an initial screening for eligibility.[3] An objective of this initial screening is to go beyond the abstracts of event reports to ensure that only events according to the work scope definition are included in the database. This screening process sometimes is less-than-straightforward. As one example, a PWR unit in 2016 experienced what initially appeared to be a minor reactor coolant pressure boundary (RCPB) leakage on a high pressure safety injection line. On closer evaluation, the leak was located on a seal weld of a threaded small-diameter connection and the leakage path was via the threads and not through-wall. Therefore, the leakage was not a RCPB leakage per ASME XI definition. Subsequently this event was not selected for inclusion 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.

3. Section 4 covers the scope of the database. Furthermore, the passive component types and failure modes to be considered are detailed in a Microsoft® Excel Workbook in which all database input parameters are detailed.

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 2.1). 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.

Table 2.1. 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

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

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

2.2. QAP scope

The QA programme covers all aspects of the CODAP project, including:

- Confidentiality (see 2.3 for additional information).
- Coding guideline (see 2.4 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 Group and must first be approved by the PRG.
- Data collection and data exchange. Data collection and coding of national data is performed by respective member country’s national co-ordinator (NC) or persons/organisations 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 co-ordinators 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 Working Group on Integrity and Ageing of Components and Structures (WGIAGE), or CNRA Working Group on Operating Experience). After completion of a review and subsequent comment resolution by the CODAP PRG, a document containing general information is published as a CSNI report.

2.3. Confidentiality

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

1. Level one. Applies to all documentation developed by the project review group. It is published on the password protected Project website. Selected level one documents may become available to interested parties via external reporting by the NEA. Examples of level one documents include the CODAP topical reports. Such documents must undergo review and approval by the CSNI prior to publication.
2. Level two. 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 authorised users. It is distributed only among active PRG members under the "Terms and Conditions for project operation," is never published on the project web site or distributed outside of the PRG.
3. Level three. 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 co-ordinator. In the web-based event database, any attachment containing proprietary information is clearly marked as a "level three" document.

The CODAP terms and conditions contain statements on the use of data within and outside the project 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 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 technical support organisations and consultants for use in specific projects, and suchlike. For this purpose, a non-confidential version of the restricted 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 co-ordinator 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. As of the date of publication of this topical report, the database has been made available to the

Nordic PSA Group (NPSAG), the Swiss nuclear plant operators, the Canadian nuclear plant operators, and certain members of the VGB PowerTech e.V. in Germany.

2.4. Coding guideline

To achieve the objectives of the CODAP project, a coding format is developed. This coding format is reflected in the coding guideline, 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.

2.5. Applications handbook

The CODAP Applications Handbook (CODAP-AH) includes guidelines for how to extract specific insights about material degradation through database interrogation, to assess failure trends and to create 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.

The 2004 workshop on OPDE applications (Seoul, Korea) identified a list of potential database applications.[4] Additional perspectives on NEA data project applications are included in the 2013 WGRISK document entitled "Use of OECD Data Project Products in Probabilistic Safety Assessment"[8].

Since the launch of OPDE in 2002, numerous database applications have been pursued to address a wide range of quantitative piping reliability analyses; see Appendix B for a listing of summary reports, conference papers and technical reports. Accompanying these applications has been methods development initiatives to advance the piping reliability analysis methodology and techniques. Most of these applications have been in the context of probabilistic safety assessment (PSA) and risk-informed applications of PSA models. Some applications have also been pursued to support structural integrity assessments using probabilistic fracture mechanics (PFM) by providing flaw initiation data and service experience data analysis results to validate the assumptions used in PFM. Practical insights from past applications form the basis for the CODAP-AH.

In its present form the online version of the CODAP event database facilitates data submissions, various search and sort functions, and database interrogation functions. The latter are performed in the QUERY area of the online database. In addition, the database may be downloaded to a local computer or computer network via a data "export function". The export function produces a XML-file[5] that can be converted to access or excel format for further data processing and analysis.

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4. OECD Nuclear Energy Agency, 2005. OECD-NEA Piping Failure Data Exchange Project (OPDE). Workshop on Database Applications, OPDE/SEC(2004)4, Seoul, Korea, 8 December 2004.

5. XML = Extensible Markup Language

Correlating the event population with the relevant plant and component populations that produced these failure events enables the estimation of reliability parameters for input to structural reliability models or PSA models. The information contained in the CODAP event database must be processed according to specific guidelines and rules to support reliability parameter estimation. A first step in this data processing involves querying the event database by applying data filters that address the conjoint requirements for pipe degradation and failure. The data filters are integral part of the database structure as defined in the CODAP-CG. Specifically, these data filters relate to unique piping reliability attributes and influence factors with respect to piping system design characteristics, design and construction practice, in-service inspection (ISI) and operating environment. The CODAP-AH consists of five parts:

1. Data exploration in the online version.
2. Exporting the CODAP event database to a local computer and converting the online database for example into a Microsoft® Access using a template.
3. Overview of basic Microsoft® Access functions.
4. Fundamentals in database query definition. SQL (or Structured Query Language) is used to manage data in relational databases such as CODAP. Database queries are defined through SQL statement definition. All applications, whether simple or advanced begin by defining queries to extract specific information from the event database.
5. Basic guidelines for the estimation of piping reliability parameters. These guidelines build on insights and results from pipe failure database applications (e.g. Appendix A). Included in this section of the CODAP-AH are descriptions of the statistical analysis tools and techniques that are compatible with the Microsoft® Access version of the database.

2.6. Data completeness

Most, if not all database applications are concerned with evaluations of event populations as a function of calendar time, operating time or component age at time of failure. The technical scope of the evaluations includes determination of trends and patterns and data homogeneity, and assessment of various statistical parameters of passive component reliability. Therefore, an intrinsic aspect of the practical database applications is the completeness and comprehensiveness of an event database. Do the results of an application correctly reflect the effectiveness of in-service inspection, ageing management, and/or water chemistry programs? Does the database capture “all” relevant operational events? In summary:

- Completeness is an indication of whether or not all the data necessary to meet current and future analysis demands are available in the database. Essentially, has the coding guideline been followed in such a way that the SEARCH and STATISTICS functions of the database produce accurate results?
- Comprehensiveness is concerned with how well CODAP captures the full and appropriate range of reliability attributes (e.g. material properties, dimensional data) and influence factors (e.g. operating environment, pipe stresses). This means that in addition to using an original event report as a base reference, additional background information such as a root cause analysis report and destructive examination results have been utilised in order to create an event record.

The completeness of the CODAP database hinges on respective national co-ordinator's data submission routines and associated local data management infrastructure. Insights and results of practical database applications are fed back to the CODAP PRG so that any identified database weaknesses, omissions or errors can be addressed and corrected in a timely manner.

2.7. Database capability categorisation

Over the years many different types of pipe failure databases have been developed [12] [13]. Relative to the intended use, maintenance/updating routines and QA, a distinction is made between "failure event database" and "reliability database". The former is a collection of raw data (or field data) on specified types of piping components or piping systems with or without database QA programme in place but with direct access to source data. Usually, a failure event database has a single user (can be a person or organisation) with sporadic or periodic database maintenance to support high-level evaluations of failure trends; it is referred to as a category one database. A reliability database includes processed raw data, is continuously updated and subjected to validation for technical accuracy and completeness and is referred to as a category two database. Some form of independent peer review normally precedes the release of a category two database for routine application by multiple users and a QA programme should be in place. Industry guides and recommendations exist for category 2 database development, structure and quality [14]. Chapters 2 and 3 of SSMFS[6] 2005:2/2008:13 [15] address the need for quality assured failure data in the context of risk-informed in-service inspection (RI-ISI). Invariably, a reliability database has multiple users engaged in PSA and risk-informed applications or advanced applications (for example expanded risk-informed application to investigate certain correlations between degradation mitigation and failure rate).

There is a third type of database, which is referred to as a category zero database; see Table 2.3 in Reference [9].It is a hybrid database, which includes some of the features found in category one and category two databases, but it is not intended to exist as a standalone, computerised database for practical use beyond an original relatively narrowly defined objective. This type of database is typically embedded as extensive tables in a technical report, sometimes as an appendix, and provides traceable background to derived piping reliability parameters included in the main body of a technical report. Historically these published category zero databases have found widespread use in risk-informed applications, however. Where this has been the case, a data user's parameter selections and justifications are rationalised by simply referencing a table in a public-domain report.

Based on their respective ability to support practical applications, SKI Report 2008:01 [9] identifies three database categories (Category zero, category one and category two). Figure 2.1 shows how these categories compare with the NEI "PSA Peer Review Guidelines" [10] grading and the ASME PRA Standard "Capability Categories" (CC) [11].

6. "Regulations & General Advice" issued by the Swedish Radiation Safety Authority (SSM).

Figure 2.1. Database Capability Categorisation

	ASME/ANS RA-Sb-2013 (September 2013) Application Capability Category[7] [11]		
	CC-I	**CC-II**	**CC-III**
NEI 00-02 PSA Peer Review Guidelines	Grade 1,2	Grade 3	Grade 4
R-Book Database Categorisation [9]	Cat0, Cat1	(Cat1) Cat2	Cat2

In risk-informed applications data quality is particularly important and necessitates considerations for traceability and reproducibility of derived reliability parameters: including the source data producing database query results and data processing and statistical analysis of query results. From a user perspective, a category two database should include detailed and correct information on failure events so that database queries generate relevant and complete results. That is, detailed information with respect to reliability attributes and influence factors. Furthermore, provisions should exist for pooling of different but relevant subsets of failure data to strengthen the statistical significance of obtained parameters. In summary, a minimum set of requirements [11] on a category two database include:

- User-friendly and flexible structure, data input forms should be designed in such a way as to encourage continuous updating by multiple operators. The structure should be flexible so that new database fields can be added if so desired.
- Clear database field definitions that reflect the attributes and influence factors that are unique to pipe degradation and failure.
- Input of raw data supported by an extensive, all-inclusive set of roll-down menus with standardised and complete set of key words.
- "All-inclusive" structure in which free-format memo fields for narrative descriptions support codification and justifications for assumptions if needed.
- Support full traceability from field data to processed data so that database users and independent reviewers have full confidence in the completeness and accuracy of database field contents.
- Configuration control including user access rules.
- Use of recognised and proven computer program(s) so that the database structure and its content remain impervious to future programme revisions and "upgrades."
- Ease of transfer of database query results to external computer programme.

7 The PSA capability categories refer to the level of detail of design information (including OE data) needed to support PSA development and application. CC-1 refers to a "base-line" PSA developed to provide relative ranking of contributors to core damage frequency. CC-II refers to plant-specific PSA in which data specialisations are performed to better characterise plant risk contributors. CC-III refers to advanced PSA applications performed in order to support changes to plant design-basis.

- Data security routines must be established to ensure that all relevant but potentially sensitive or proprietary failure information is captured in the database. Also routines must exist for proper sharing of information among multiple users.
- Detailed database documentation including coding guideline to ensure proper technology transfer.
- Approved QA program. To be effective a QA programme should reflect a consensus perspective on data quality. The prospective database users must have a common understanding of intended usage and steps that are required to ensure configuration control and validation of database records.
- Completeness of database should be ensured through continuous or at least periodic updating. Completeness is concerned with event populations and assurances that "all" relevant events are captured. It is also concerned with completeness of the classification of each database record. Ultimately "completeness" has direct bearing on the statistical significance of derived reliability parameters.

This "requirements list" for a category two database such as CODAP is not an all-inclusive list. Depending on the number of database users and type of application that is being pursued, additional requirements could be defined. Fundamentally, a database for risk-informed applications should be robust in the sense that it must support a broad range of applications, including repeat applications, and provide analysts with a solid knowledgebase for database query definition. Ideally a reliability database should be self-contained so that it includes all facts about the cause-and-consequence of any degraded condition recorded in it. Why was it recorded in the first place, what were the material specifications and operating conditions, and exactly where in a piping system did the failure occur?

3. Passive component degradation and failure

The metallic passive component physics-of-degradation/failure is determined by metals-environment systems, localised loading or stress conditions, and methods of fabrication/installation. The interactions between the various controlling parameters are conjoint. That is, all of the individual conditions for the controlling parameters must be met for a given degree of material degradation. Therefore, the structure of a passive component failure database like CODAP needs to capture a relatively large number of physical parameters to correctly characterise the cause and underlying contributing factors of a certain degraded or failed condition. This section is an overview of metallic passive component degradation mechanisms and the consequential requirements for a comprehensive operating experience database structure.

3.1. Apparent cause and contributing factors

In the coding of an event according to the primary degradation mechanism that caused the failure, the data analyst relies on the information contained in an event report and any supporting information such as a root cause analysis report that may include results from a non-destructive examination. The CODAP coding guideline provides basic information the coding; Figure 3.1. Correct coding of an event relies as much on the available information in an event report as on the analyst's knowledge of material science, piping design principles, nuclear plant operations principles, non-destructive examination technologies, and past component field experience. In many cases the coding can be quite challenging. Sections 3.2 through 3.7 document the basic considerations that enter into the process of ensuring that the coding process is accurate and complete relative to the apparent cause and contributing factors.

3.2. Metallic passive component degradation/failure manifestations

The causes of passive component degradation or failure (e.g. loss of structural integrity, through-wall leak) are attributed to various damage or degradation mechanisms. Passive component failure occurs due to synergistic effects involving operating environment and loading conditions. CODAP considers two classes of passive component failure types:

- Event-driven failures. These failures are mechanically stress driven and attributed to conditions involving combinations of equipment failures (other than the piping itself; e.g. loose/failed pipe support, leaking valve) and stress risers or unanticipated loading conditions (e.g. hydraulic transient or operator error). Examples of event-based failures include various fatigue failures such as low/high-cycle vibration fatigue and thermal fatigue.
- Failures attributed to time-dependent environmental degradation. Environmental degradation is defined by unique sets of conjoint requirements that include operating environment, material and loading conditions. These conjoint requirements differ extensively across different piping designs (material, diameter, wall thickness,

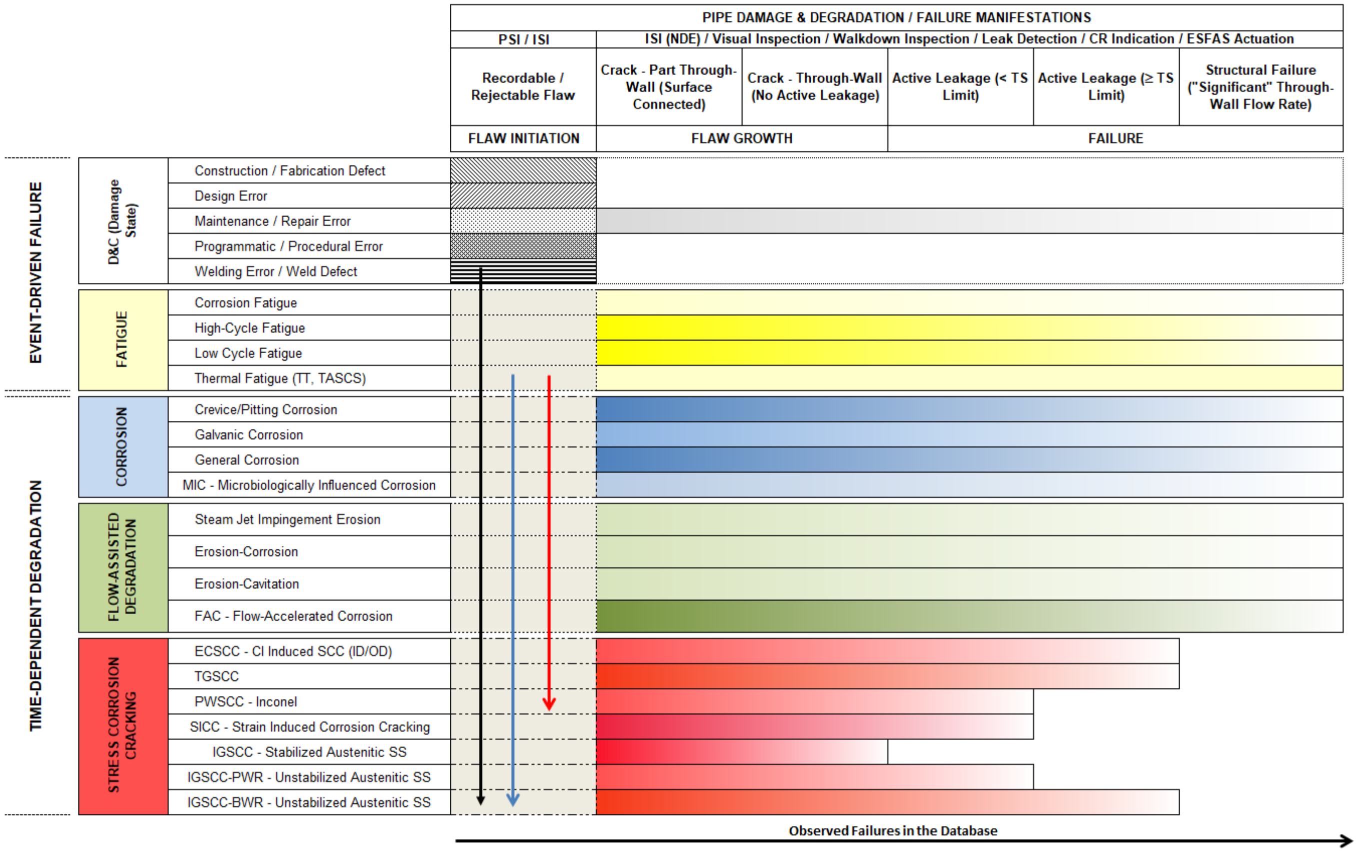
method of construction/fabrications). Similarly, pipe flaw incubation times and flaw growth rates differ extensively across the different combinations of degradation susceptibility and operating environments.

As recorded in CODAP, synthesised in Figure 3.2 is the entire body of field experience with metallic piping in commercial nuclear power plants. Included in this figure are the many unique failure manifestations of concern in the codification of field experience data.

Figure 3.1. Codification of Apparent Cause of Degradation/Failure & Underlying Contributing Factors

Apparent Cause	Environment	Material	Stress/Loading	Other
Boric Acid Corrosion	Blockage	Cold Worked	Bending Stresses Due to Constrained Assembly Conditions	HF:Construction/Installation Error
Corrosion	Cavitation	Improper Material Selection	Damaged/Loose Pipe Support	HF:Design Error
Corrosion-External	Contamination	Increased Concentration of Inclusions	External Impact	HF:Human Error
Corrosion-Fatigue - CF	Contamination - Chlorides	Material Susceptible to SCC	High Residual Stresses	HF:Fabrication Error
Corrosion - Galvanic	Damaged Liner		Inadequate Pipe Support	HF:ISI Program Failure
Corrosion-Pitting	Degraded Coating		Stress Riser due to Root Notch	HF:Procedural Error
Crevice Corrosion	Degraded Moisture Barrier		Water Hammer - Hydraulic Transient	HF:Repair/Maintenance Error
Dealloying - Selective Leaching	Demin. Breakdown - pH Decrease			HF:Welding Error
Delayed Hydride Cracking	Entrapped Air/Voiding			
ECSCC - External Chloride Induced SCC	Freezing			
Erosion	High Nitrate Level			
Erosion-Cavitation	Loss of Heat Tracing			
Erosion-Corrosion	Low O2 Content			
Excessive Vibration				
FAC - Flow Accelerated Corrosion				
Fatigue				
Fretting				
High-Cycle Fatigue				
Hydrogen Embrittlement				
Hydrogen-Induced SCC				
IASCC - Irradiation Assisted SCC				
IDSCC - Interdendritic SCC				
IGSCC - Intergranular SCC				
Intergranular Corrosion - IGC				
Jet Impingement Erosion				
Low-Cycle Fatigue				
Low-Cycle Fatigue Pressure Loads				
MIC - Microbiologically Influenced Corrosion				
N/A - None				
Overpressurized				
Overstressed				
Preferential Corrosion				
PWSCC				
Severe Overloading				
SICC - Strain Induced Corrosion Cracking				
TGSCC - Transgranular SCC				
Thermal Aging Embrittlement				
Thermal Fatigue - Cycling				
Thermal Fatigue - Stratification				
Vibration-Fatigue				

Figure 3.2. Metallic Passive Component Failure Manifestations[8]



8. The vertical arrows indicate the presence of potential or actual *synergistic effects*. For example, thermal fatigue may cause crack initiation, and crack propagation may occur via IGSCC. The fill-effects in the colourised horizontal bars are commensurate with the observed event populations; i.e. a strong fill corresponds 'multiple' events and a weak fill corresponds 'relatively few' major structural failures.

A "failure" is any degraded condition that necessitates repair or replacement. The "magnitude" of a failure manifestation is assessed through non-destructive/destructive examination, visual examination or metallographic examination. Through-wall defects are characterised by the size of a flaw and resulting mass or volumetric leak or flow rate (from perceptible leakage to gross leakage). Some combinations of material, operating environments have produced "major structural failures" while certain other combinations have produced only minor flaws. For example, stainless steel piping has not experienced any major structural failures, while carbon steel in wet steam environment has experienced major structural failures. According to this failure synthesis, certain combinations of material, loading, and environmental conditions have produced major structural failures. For such combinations direct estimation of pipe break frequencies is feasible. In contrast, stress corrosion cracking (SCC) induced major structural failures have not been experienced. Development of a conditional rupture probability model for SCC requires a probabilistic fracture mechanics approach and with possible input from an expert elicitation process.

In Figure 3.2 the downward arrows symbolise the potential synergistic effects of various damage and degradation mechanisms. As one example, various types of weld defects (e.g. lack of fusion, slag inclusions) tend to be a strong contributor to crack initiation sites that ultimately result in stress corrosion cracking (SCC) failure. As another example, thermal fatigue can cause crack initiation while a SCC mechanism can cause crack propagation in a pipe through-wall direction.

Noteworthy is the fact that certain combinations of metals/environment systems, localised loading or stress conditions, and methods of fabrication/installation have produced major structural failures while other combinations at most have resulted in relatively minor through-wall flaw. An event database such as CODAP documents historical information and does not provide predictions about the long-term structural integrity. However, it does enable the assessment of temporal trends in metallic material performance. An objective of CODAP is to address ageing and the positive and potentially negative effects degradation mitigation initiatives.

3.3. Design and construction (D&C) defects

A generic insight from piping failure root cause analyses points to the significance of human error (or organisational factor) contributions. Official process industry incident statistics show that 20% to 90% of all incidents are indirectly or directly caused by human error. Human errors are either latent or active; c.f. Reason [16] and Embrey et al [17]. Effects of a latent error may lie dormant within a system for a long time, only becoming evident after a period of time when the condition caused by the error combines with other errors or particular operating conditions. An example of latent error affecting piping reliability is the design or construction error first revealed, say, several years after commercial operation began. A root cause of such an error could be lack of design knowledge. Another example of latent human error affecting piping reliability is the maintenance and ISI-policy that does not acknowledge existing, generic operating experience with a particular type of piping system. By contrast, effects of an active human error are felt almost immediately; e.g. water hammer due to improper post-maintenance restoration of a piping system.

Studies have been performed to assess the human error contributions to piping failure [18][19]. Hurst et al. [18] analysed piping failures in the chemical process industry. This

British study shows that "operating error" was the largest immediate contributor to piping failure (30.9% of all known causes). Overpressure (20.5%) and corrosion (15.6%) were the next largest categories of known immediate causes. The other major areas of human contribution to immediate causes were human initiated impact (5.6%) and incorrect installation of equipment (4.5%). The total human contribution to immediate causes was therefore about 41%. For the underlying causes of piping failure, maintenance (38.7%) and design (26.7%) were the largest contributors. The largest potential preventive mechanisms were human factors review (29.5%), hazard study (25.4%) and checking and testing of completed tasks (24.4%). A key conclusion of the study was that based on the data analysis, about 90% of all failure events would be potentially within the control of management to prevent.

3.3.1. D&C event sequence diagram

Service-induced degradation of reactor components results from synergies among material characteristics, loading (e.g. stress riser), and environmental conditions (e.g. flow conditions, water chemistry). Through-wall pipe flaws involve initiation and incubation. That is, a pre-existing flaw acting as a stress riser (e.g. an embedded slag inclusion in a weld) or is exposed to an adverse environment that eventually progresses to a through-wall defect or non-through-wall defect that is connected to the inside surface of a pipe. The majority of pipe flaws that result in a corrective action (repair or replacement) are attributed to a readily identifiable active degradation mechanism or an off-normal loading condition. An example of the latter can be high-cycle mechanical fatigue caused by a failed pipe support.

A relatively small subset of all recordable or rejectable pipe failures involves a pre-existing defect that over long time grows and is detected through a surface examination (e.g. visual examination or liquid penetrant testing). The D&C event sequence diagram in Figure 3.3 illustrates the classification of weld flaws for which no active degradation mechanism is present. Code class one welds are subjected to pre-service inspection (PSI) and rejectable flaws are repaired. There is some likelihood that a pre-existing flaw is not detected, however. Again, an in-service inspection (ISI) may/may not detect a weld defect. If successfully detected, the weld defect is evaluated per ISI program acceptance standards. Continued operation is possible if repair/replacement is performed or some degradation mitigation is implemented.

Assuming that a pre-existing flaw is discovered during an ISI but remains unmitigated (i.e. no repair is performed) then crack growth may occur given that it is subjected to an adverse operating environment (high temperature and corrosive) and the material is susceptible to degradation. The potential of through-wall cracking (TWC) would be high if the conjoint requirements for degradation are met ("TWC Potential-H" in Figure 3.3). In developing an initiating event frequency model, pipe failure rates and rupture probabilities are derived for all piping components within the evaluation boundaries. The piping reliability parameter estimation process considers all credible damage and degradation mechanisms that apply to an evaluation boundary. For locations without any readily identifiable damage or degradation susceptibility an assumption is made that a pre-existing weld flaw may exist and eventually grow in the through-wall direction. The flaw growth mechanism is termed "low-cycle fatigue and pressure loading" (LC-FAT) and accounts for the effects of normal operation including cool-down and heat-cycles. Therefore, a CRP model is needed to resolve the LCF analysis cases. Figure 3.3 displays two event sequence paths that are highlighted in red that represent the high likelihood of a pre-existing defect growing into a through-wall crack (TWC).

3.3.2. Effect of welding process on degradation susceptibility

The operating experience data classification in CODAP differentiates between field welds and shop welds. High-level database summaries are included in Figures 3.4 through Figure 3.6. In Figure 3.4 the entire database content is organised according the location of a flaw; base metal or weld metal/weld-HAZ. Limited to Code class one piping, Figure 3.5 shows the number of failure records by weld type. Figure 3.6 shows the results of the following database queries:

- field weld/shop weld failures for which no active degradation mechanism contributed to the flaw discovery;
- field weld/shop weld failures attributed to an active degradation mechanism with or without contribution from an initial weld defect.

Figure 3.3. D&C event sequence diagram

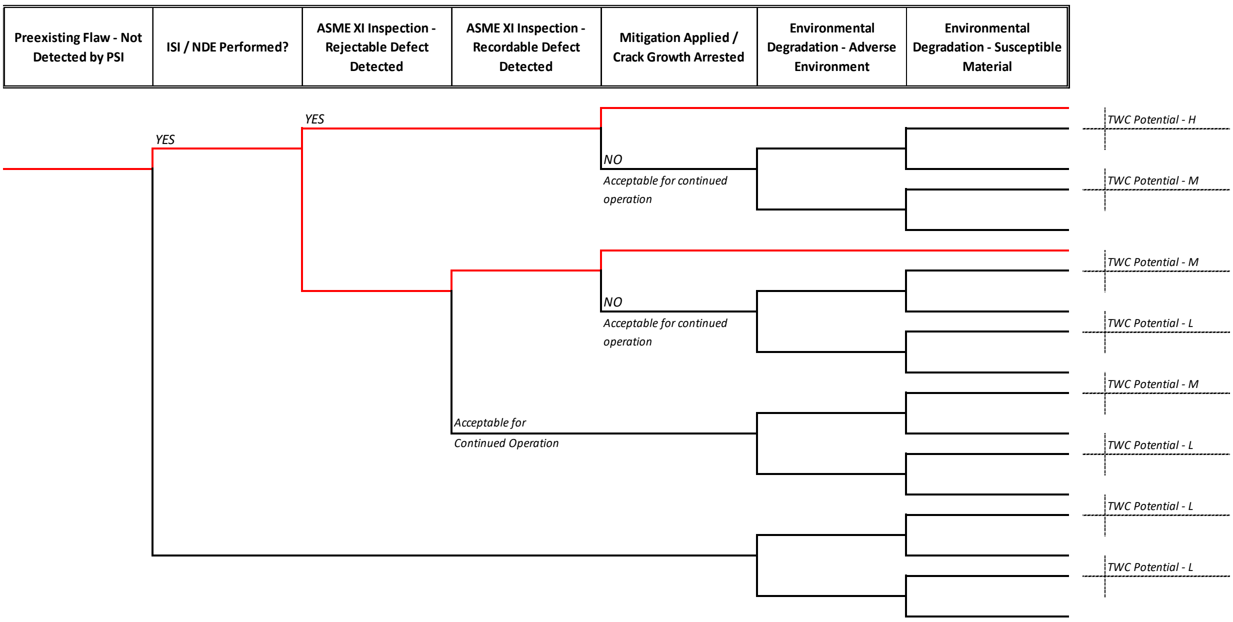
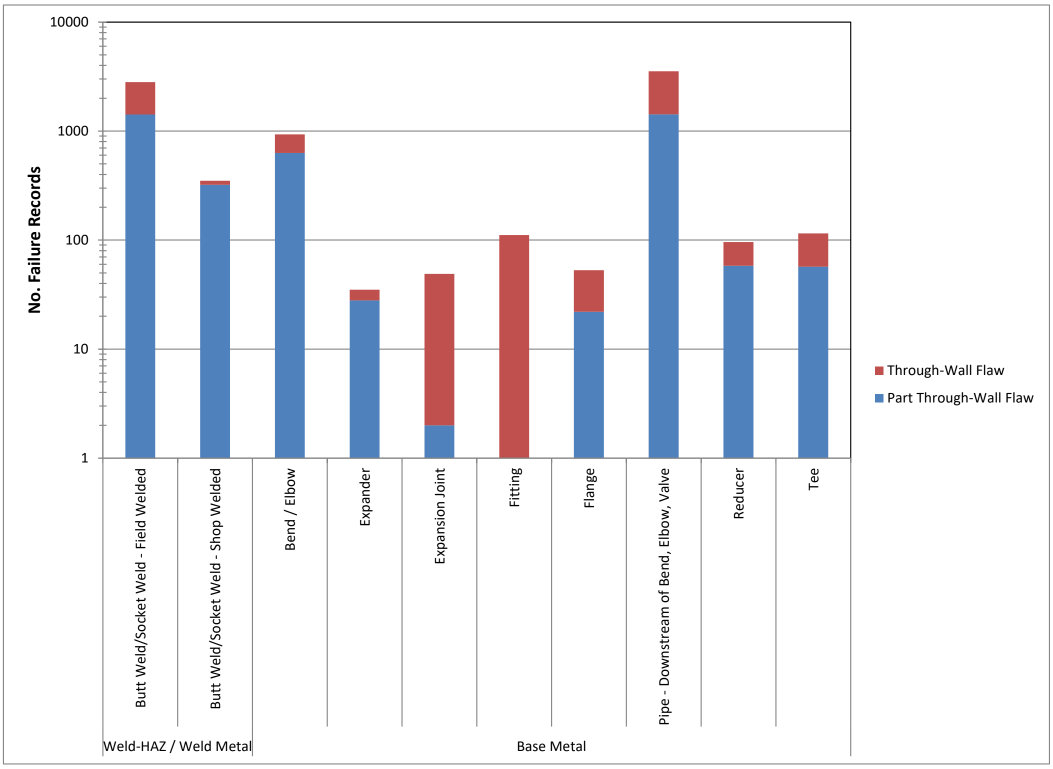


Figure 3.4. Pipe Failure by Component Type



Several qualitative insights can be drawn from these query results. For small-bore piping, only a relatively few failures of shop welds have been reported. This is to be expected since the majority of the small-bore lines (e.g. drain lines, instrument lines, vent lines) consist of field welded piping/tubing. The majority (89%) of all reported shop weld failures involve piping of nominal pipe size greater than DN100 (4”) and with an active degradation mechanism as the “apparent cause of failure.” Further review of this larger subpopulation reveals that approximately 79% of the shop weld failures involve boiling water reactor (BWR) Reactor Recirculation system welds that have failed due to intergranular stress corrosion cracking (IGSCC); Figure 3.7.

Figure 3.5. Safety Class 1 Pipe Failures

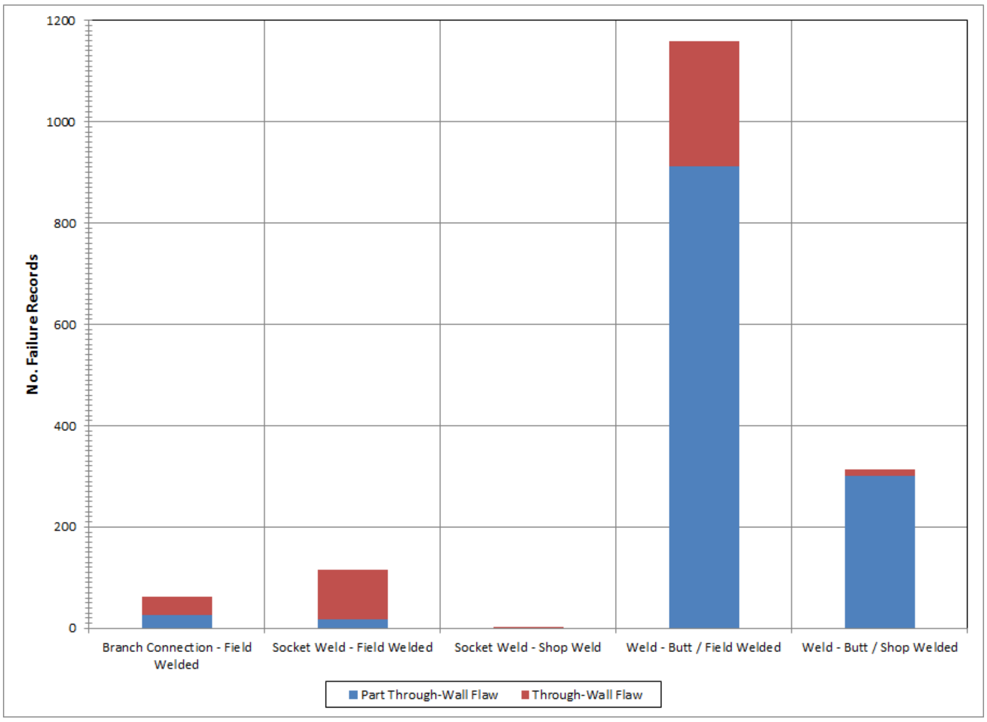
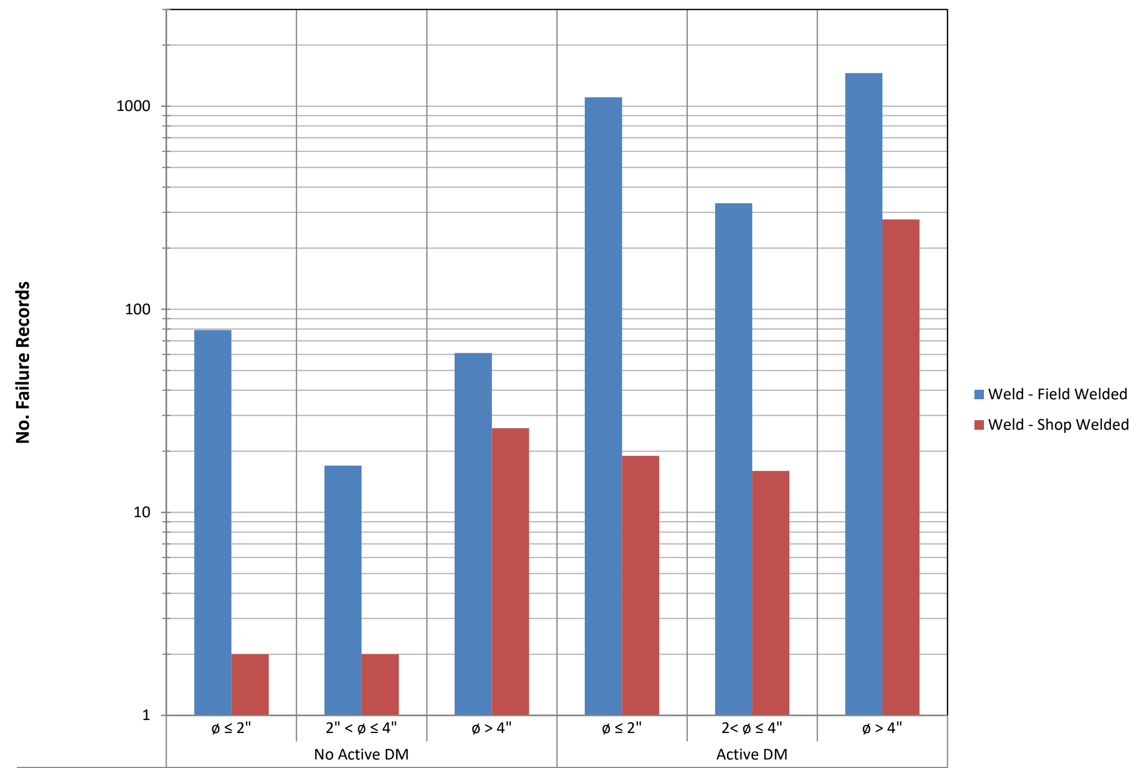


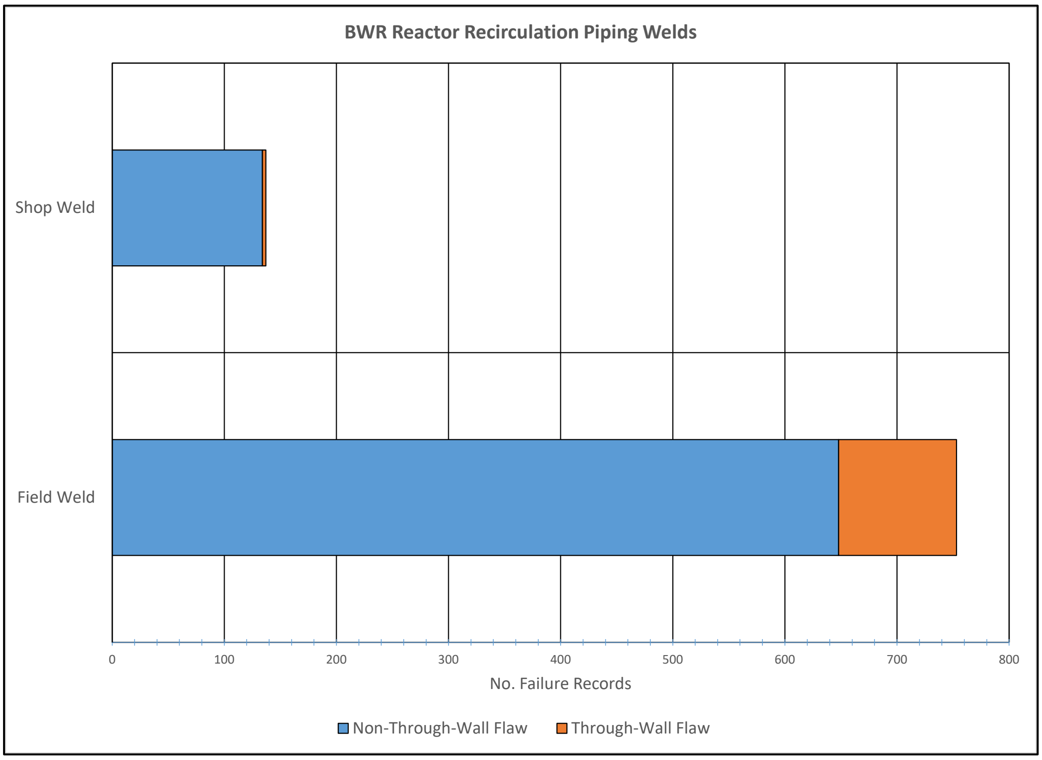
Figure 3.6. Operating Experience with Safety Class 1 Field & Shop Welds



	No Active DM ø ≤ 2"	No Active DM 2" < ø ≤ 4"	No Active DM ø > 4"	Active DM ø ≤ 2"	Active DM 2< ø ≤ 4"	Active DM ø > 4"
Weld - Field Welded	79	17	61	1106	333	1455
Weld - Shop Welded	2	2	26	19	16	277

:

Figure 3.7. BWR Safety Class IGSCC Failure Data



In BWR plants with external recirculation loops, approximately 40% of the welds are shop welded. In contrast to the BWR plants and with the exception for pipe-to-safe-end welds, all code class one pressurised water reactor (PWR) reactor coolant system (RCS) hot leg, cold leg and surge line welds are shop welded.

The majority of the recorded shop weld failures have occurred in large-bore stainless steel piping susceptible to IGSCC. This form of stress corrosion cracking develops as the result of weld sensitisation of the weld heat-affected zone and weld metal hot cracking, tensile stresses and corrosive environment. The welding process induces residual tensile stress that is detrimental to fatigue life. Tensile stresses act to stretch or pull apart the surface of the material. With enough load cycles at a high enough tensile stress, a metal surface will initiate a crack. Weld residual stresses have been measured in a variety of stainless steel grades and pipe sizes using strain-gage and X-ray methods. These residual stresses are a major contributor to the overall tensile stresses acting on a pipe weldment.

Sensitisation-related remedies include solution heat treatment, corrosion-resistant cladding, and alternative pipe materials. Solution heat treatment is used for shop welds. It reduces or eliminates weld sensitisation, residual stresses, and the effects of machining and grinding.

The welding process affects the final weld microstructure and hence the mechanical properties. For shop welds in BWR primary system piping, submerged arc welding (SAW) has been used. Field welding typically has used shielded metal arc welding (SMAW) and gas tungsten arc welding (GTAW). Typically, manual GTAW has been used for root pass followed by either SMAW or automated GTAW. The best balance of strength and toughness is produced by GTAW followed by SMAW. According to some researchers, the SAW method produces an acceptable but less desirable balance of mechanical properties.

The weld preparation method influences IGSCC initiation and propagation. In preparing the piping for welding, the inside surface is machined or ground to match the two pipe pieces to be welded together. Depending on the pipe diameter, post-weld grinding may also be used to clean up the weld for inspection. The method of surface preparation will affect the surface residual stresses. Heavy machining and grinding will result in cold working, high residual stresses, and areas of stress intensification. These cold-worked areas will also result in surface re-crystallisation during welding. All of these changes enhance the initiation process of IGSCC.

To explore the positive effect of a good welding process on the IGSCC susceptibility the available BWR-specific IGSCC operating experience is explored in further detail. Extensive service experience data exists on BWR code class one stress corrosion cracking incidents in large-bore stainless steel piping.

It is noteworthy that reactor coolant purity and corrosion potential can have a marked effect on the cracking susceptibility. Changes in water conductivity and in oxidising conditions have changed markedly over time. Early operations under poor water purity control can have a marked effect on the cracking susceptibility even upon subsequent improved purity control. Thus, the times to crack detection under these conditions are not comparable with those obtained where the water purity has been maintained throughout operations. Calculated prior and posterior weld failure rates are included in Figure 3.8, and best estimate weld failure rates for different pipe sizes and non-through-wall (NTW) cracks are included in Figure 3.9. These simplified calculations do not account for plant-to-plant variability in water purity control, however.

Figure 3.8. Calculated Failure Rates for NPS28 Stainless Steel Welds

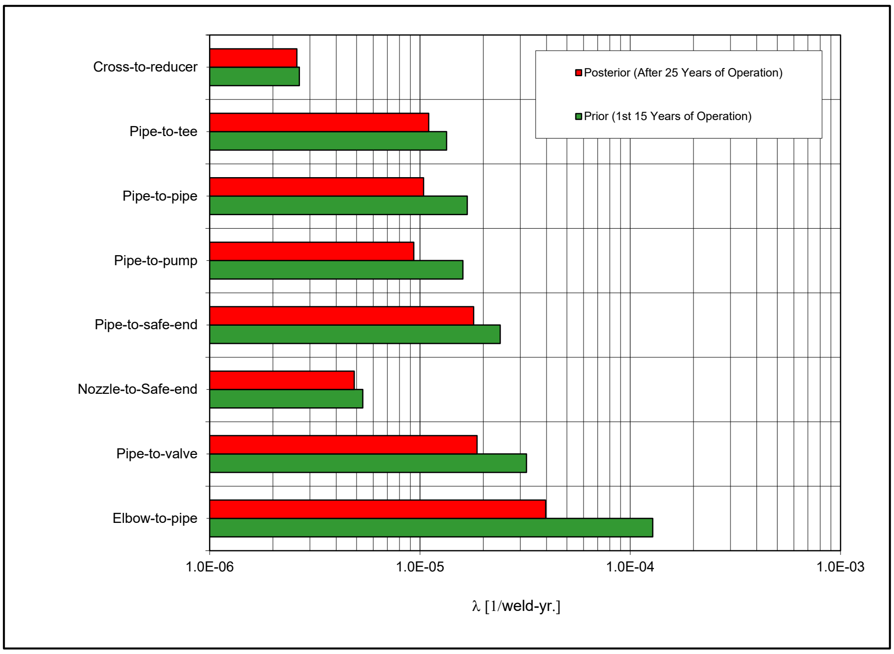
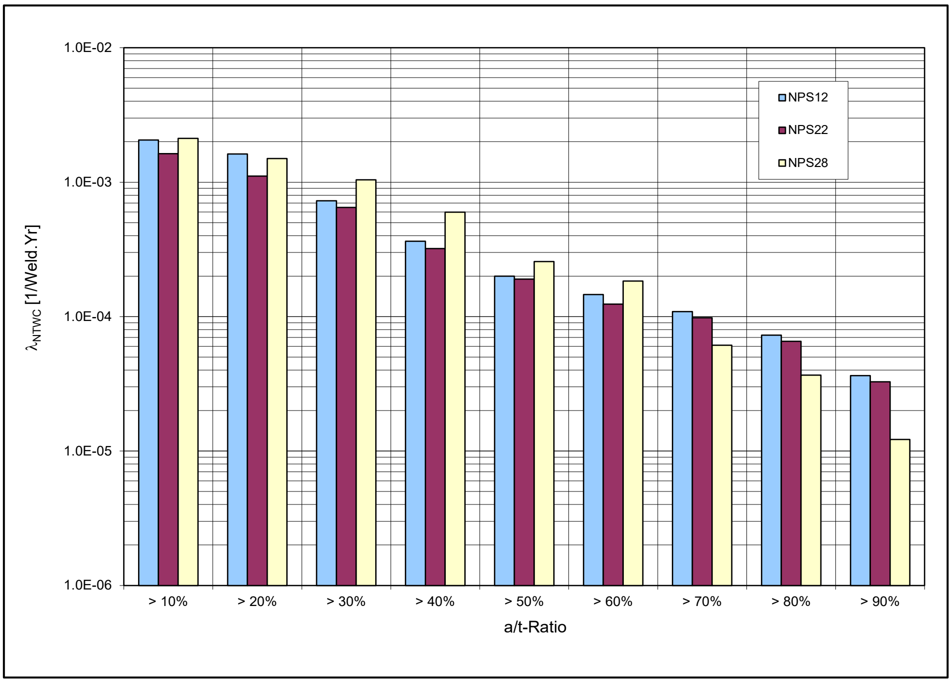


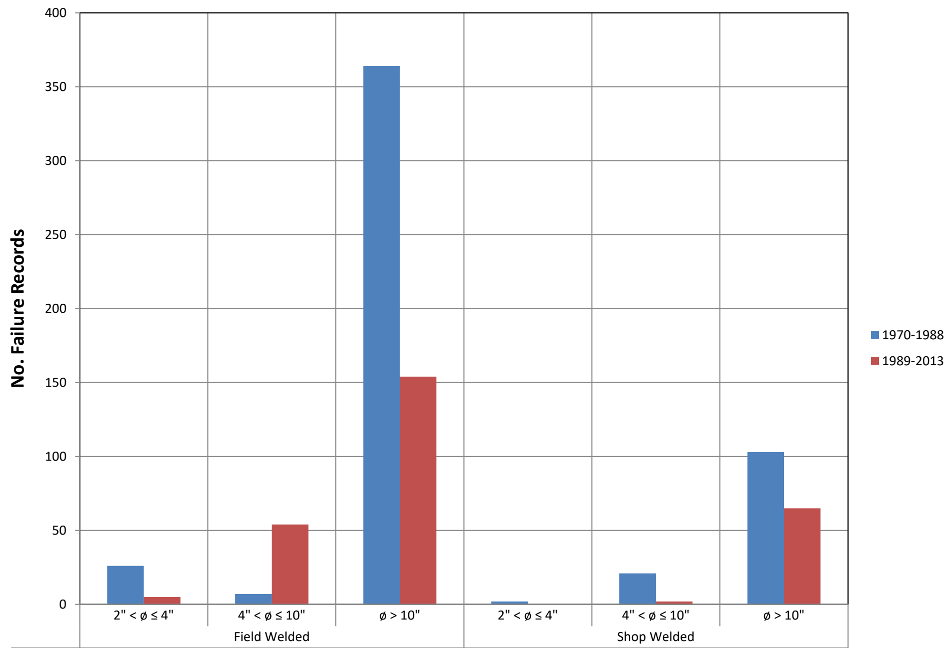
Figure 3.8. Calculated Weld Failure Rates Conditional on Crack Depth



For shop welds, two cases are evaluated: 1) "LTA WPS", and 2) "Screened Data." A careful review of the post-1989 service experience data reveals an interesting sub-population for which detailed root cause analysis results are available. At three multi-unit BWR plant sites, a shared, less-than-adequate (LTA) welding process specification (WPS) had been applied. Excessive grinding and polishing of the inside diameter of the weldments generated high residual stresses that contributed to failure of these welds. Case two, with this subpopulation is screened out, represents a projected weld failure rate for "IGSCC susceptible environment" and high quality welding process.

The event population data for calculation case #two (posterior weld failure) is summarised in Figure 3.10. The failure data is organised by time period (failures during 1970 through 1988 and failures during 1989 to date) and pipe size. Splitting of the data in two time periods is done to address the impact of IGSCC mitigation strategies post-1988 (implementation of U.S. NRC Generic Letter 88-01 [2[20]]). These mitigation strategies include improved primary water chemistry and transition from Normal Water Chemistry (NWC) to Hydrogen Water Chemistry (HWC). In modelling the field weld and shop weld reliability an attempt was made to filter out the effects on IGSCC susceptibility by water chemistry and weld stresses.

Figure 3.90. BWR Reactor Recirculation System Weld Failure Data

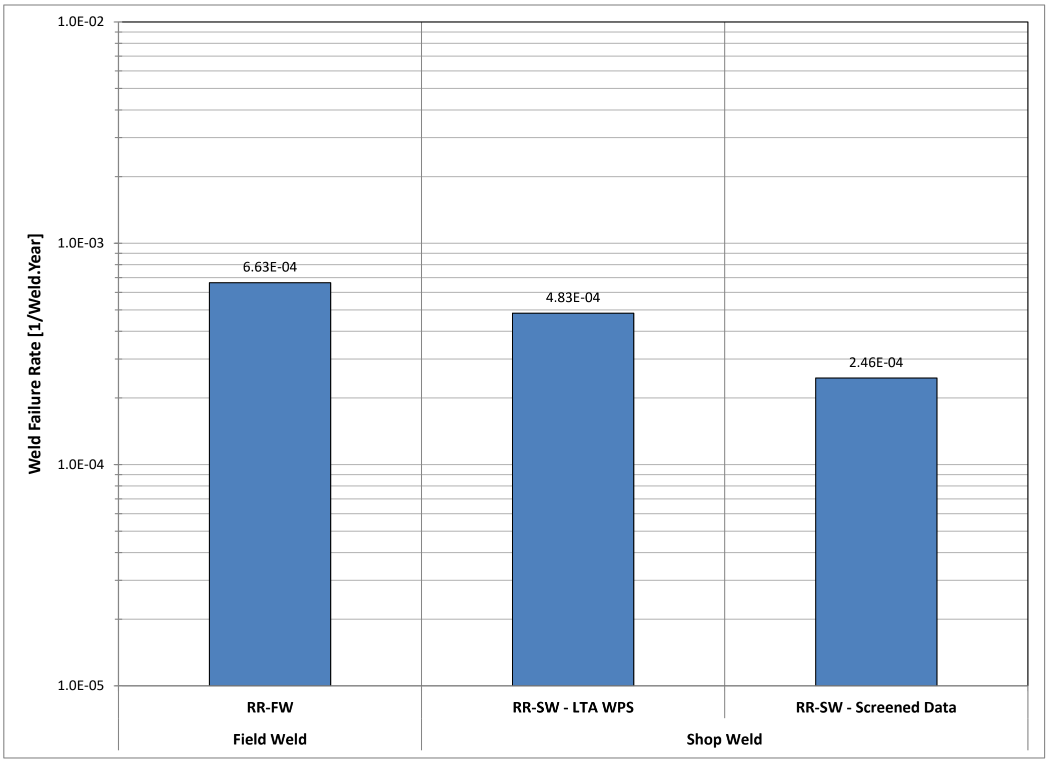


	Field Welded			Shop Welded		
	2" < ø ≤ 4"	4" < ø ≤ 10"	ø > 10"	2" < ø ≤ 4"	4" < ø ≤ 10"	ø > 10"
1970-1988	26	7	364	2	21	103
1989-2013	5	54	154	0	2	65

In calculating the FW and SW failure rates the exposure term consists of respective weld population multiplied by the number BWR plant years of operation. Only BWR plants with external recirculation loops are considered. There is plant-to-plant variability in the weld populations. On average, about 40% of the total Reactor Recirculation (RR) system weld population consists of shop welds. In this analysis, an isometric drawing review was performed on three plants, resulting in a mid-point value of 71 shop welds and 123 field welds. At the time of this analysis there were 2,890 reactor operating years of external RR-loop plant experience; 936 reactor years for the period 1970-1988 and 1,900 reactor years for the period 1989-2013.

The results of the weld failure calculation are summarised in Figure 3.11. The shop weld failure population > 10” diameter for the period 1989-2013 includes a significant subpopulation (32 records) consisting a small group of plants for which the root cause analyses pointed to a deficient weld procedure specification resulting in excessive cold working during the fit-up process. Screening out this subpopulation does impact the calculated weld failure rate.

Figure 3.11. Calculated Field Weld & Shop Weld Failure Rates (> 10")



3.4. Fatigue of piping components

According to ASTM International[9], fatigue is "the process of progressive localised permanent structural change occurring in material subjected to conditions which produce fluctuating stresses and strains at some point or points and which may culminate in crack or complete fracture after a sufficient number of fluctuations." The CODAP event database captures four basic types of fatigue mechanisms: 1) corrosion-fatigue (C-F), 2) low-cycle fatigue (LCF), 3) thermal fatigue (TF), and 4) high-cycle fatigue (HCF). Approximately 80% of the recorded fatigue failures recorded in CODAP are due to vibration fatigue of small-diameter butt welds and socket welds.

Corrosion-fatigue is (C-F) the result of the combined action of alternating or cyclic stresses and a corrosive environment. The fatigue process is thought to cause rupture of the protective passive film, upon which corrosion is accelerated. In a corrosive environment the stress level at which it could be assumed a material has infinite life is lowered or non-existent. Contrary to a pure mechanical fatigue, there is no fatigue limit load in corrosion-assisted fatigue. Much lower failure stresses and much shorter failure times can occur in a corrosive environment than in a non-corrosive environment. The fatigue fracture and the cracks are most often transgranular, but not branched. Mitigation of corrosion-fatigue can be accomplished using corrosion resistant materials in combination with stress reduction strategies, for example by stress redistribution.

In CODAP the corrosion-fatigue event population is small; a total of 27 recorded events most of which involve recordable/rejectable indications per the definitions of ASME

9. Known until 2001 as the American Society for Testing & Materials

Section XI (Rules for Inservice Inspection of Nuclear Power Plant Components). An example of material degradation induced by corrosion-fatigue is that found through metallographic examination of cracked code class two feedwater reducers at the now decommissioned Trojan nuclear power plant in 1987. The most significant corrosion-fatigue failure to date is the major primary coolant leakage that occurred at the Russian plant Kola unit two on 3 March 1994 when a two-inch make-up system pipe ruptured[10].

In the CODAP event database, the term "low-cycle fatigue" is used to characterise crack growth in the pipe through-wall direction through applied stress and normally occurring cooldown/heatup cycles. An underlying assumption is that of a pre-existing weld flaw attributed to original construction, fabrication or welding defects missed by pre-service inspections and/or subsequent in-service inspections. According to the Coding Guideline, the following conditions must be met for an event to be classified as LCF: 1) no active environmental degradation mechanism can be identified, and 2) the root cause evaluation points to presence of a weld flaw such as lack of fusion is one possible cause. Approximately 8% of the fatigue failures recorded in CODAP are attributed to LCF and of this event population, about 75% involve piping of ≤ DN50.

Thermal fatigue is due to the cyclic stresses that result from changing temperature conditions in a component or in the piping attached to the component. Thermal fatigue may involve a relatively low number of cycles at a higher strain (e.g. plant operational cycles or injection of cold water into a hot nozzle) or due to a high number of cycles at low stress amplitude (e.g. local leakage effects or cyclic stratification).

High-cycle fatigue (HCF) involves a high number of cycles at relatively low stress amplitudes (typically below the material's yield strength but above the fatigue endurance limit of the material). The crack initiation phase is considered to be dominant, since crack growth is usually fairly rapid. High cycle fatigue may be due to vibration or pressure pulses or due to flow-induced vibration (FIV). FIV can induce high-cycle fatigue (HCF) through interaction with flow adjacent to the component or within the system, establishing a cyclic stress response in the component. Power uprate is also of concern as an increase in flow may change the vibrational characteristics of the system and in the worst case excite a HC mode where a resonant frequency is achieved. Of the total high-cycle fatigue event population, approximately 40% involve socket weld failures. The CODAP event database addresses the potential negative influences of power uprate on fatigue tolerance. To date only a handful of database records have been classified as failures due to FIV and as a direct consequence of power uprates, however.

3.4.1. Fatigue-induced EHC piping failures

The Electro-Hydraulic Control (EHC) system is a non-safety-related system consisting of small-diameter piping. Failures of EHC piping have resulted in reactor trip and safety system actuation. From its inception, CODAP has collected operating experience data involving small-diameter (≤ DN25) piping failure. Turbine trip and reactor trip following an EHC pipe break are not uncommon occurrences. The observed impact of EHC pipe failure on plant operation is illustrated in Figure 3.12. In the CODAP Event Database the EHC pipe failure population consists of 83 records [[5]. In Figure 3.13 the EHC pipe failure population is organised by damage and degradation mechanism.

10. International Atomic Energy Agency, Draft Report of a Consultants Meeting on a Primary Coolant Leak at Kola two NPP Due to the Rupture of a Make-up Pipe. WWER-SC-112, Vienna, Austria, 1995.

3.4.2. Socket weld integrity management

There have been frequent occurrences of high-cycle fatigue failures of socket welded connections in safety related piping systems; Figure 3.14. NUREG-1801 [[21] documents a technical basis for determining the adequacy of ageing management programmes (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 one piping should be included for piping less than DN100. Other ASME Code provisions exempt from examination piping of size DN25 and smaller. This programme is augmented to include piping from DN25 to less than DN100. Also, Examination Category B-P requires system leakage testing of all class one piping.

According to the USNRC [[21], 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 one weld is removed. These examinations provide additional assurance that either ageing of small-bore ASME code class one piping is not occurring or the ageing is insignificant, such that a plant-specific ageing management program (AMP) is not warranted and is applicable to small-bore ASME code class one piping and systems less than DN100 and greater than or equal to DN25. The programme includes pipes, fittings, branch connections, and all full and partial penetration (socket) welds.

Figure 3.12. Impact on Plant Operation by EHC & Instrument Air (IA) Pipe Failure

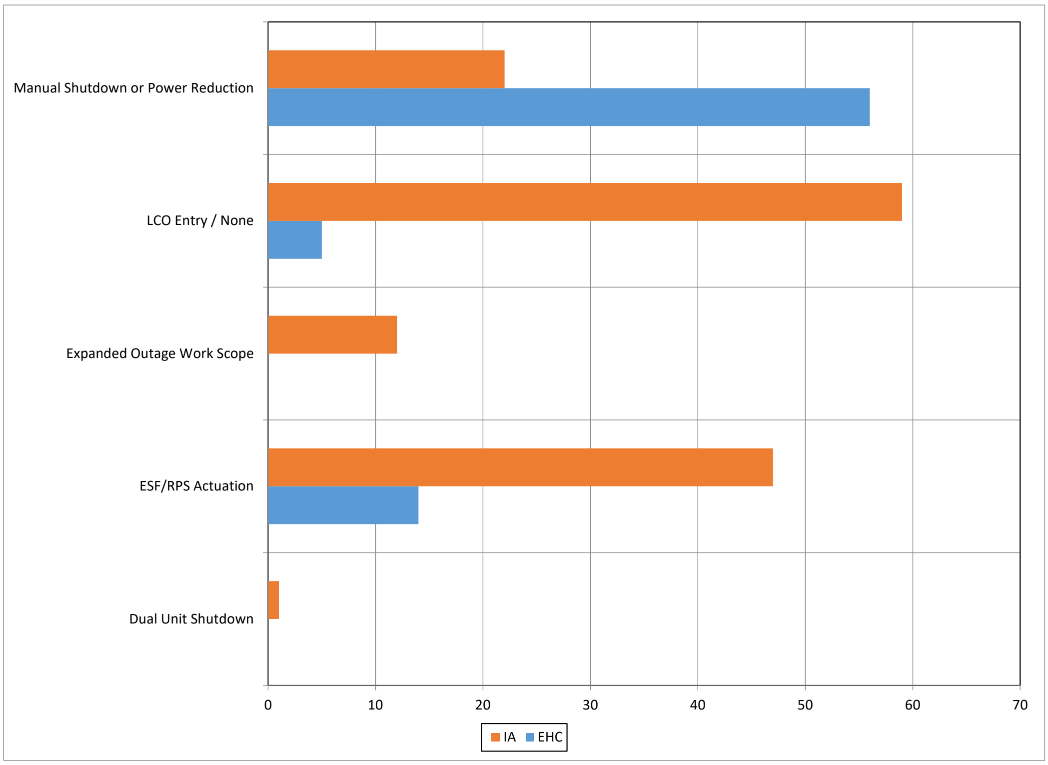


Figure 3.13. EHC & IA Piping Degradation Mechanisms

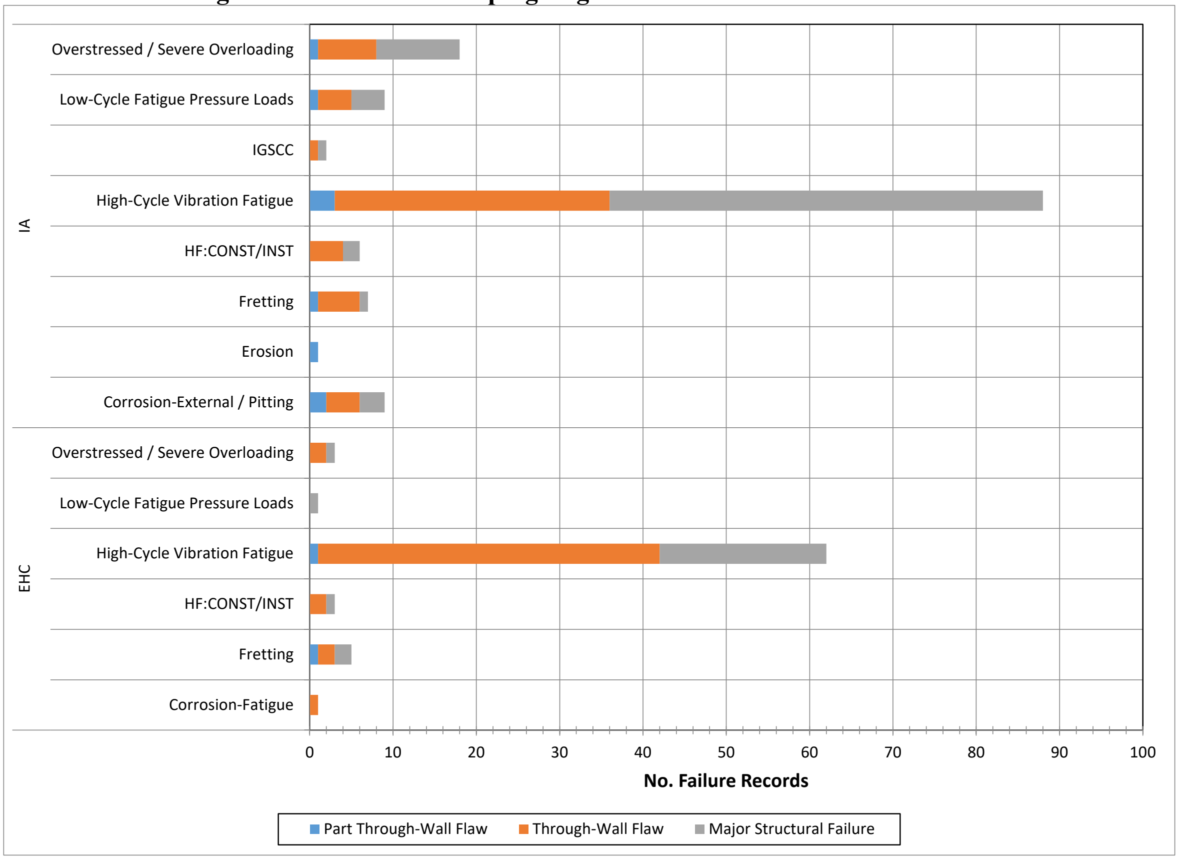
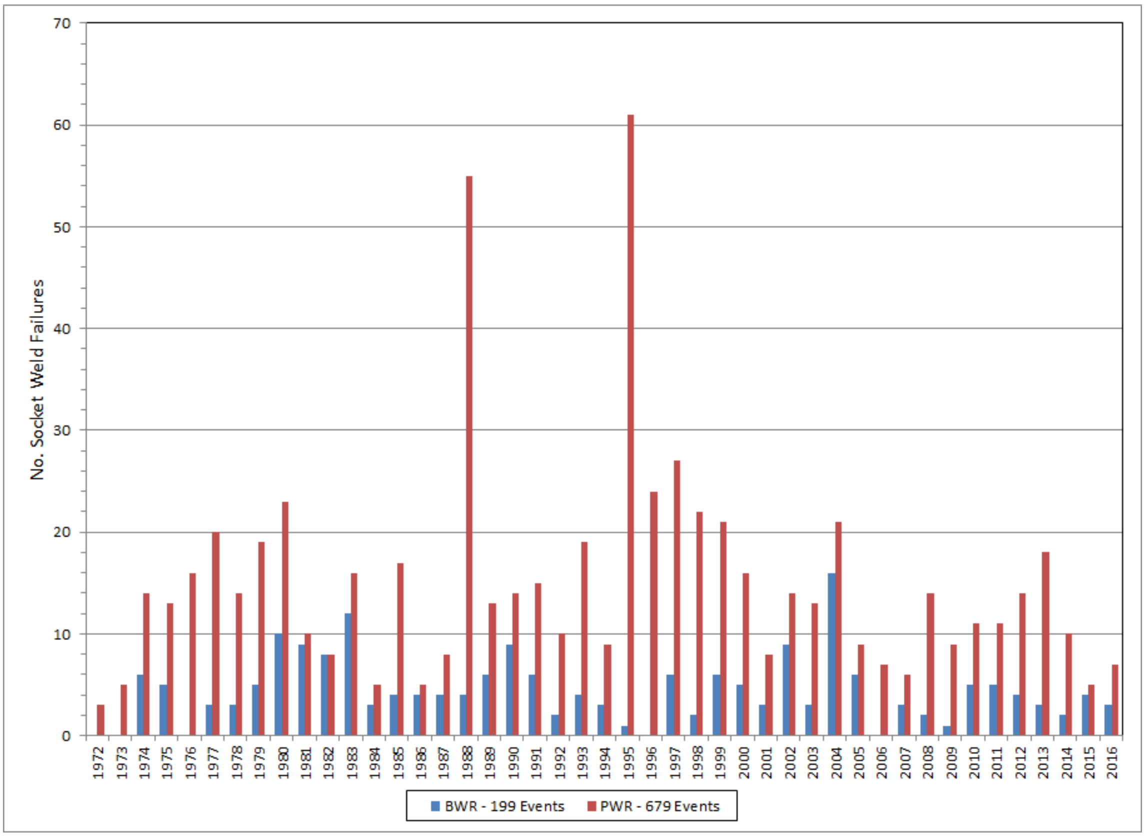


Figure 3.14. Socket Weld Failure Summary



3.5. Corrosion fatigue

Corrosion fatigue or "environmentally assisted fatigue" is the behaviour of materials under cyclic loading conditions and in a corrosive environment. It is considered to be made up of a region (or life) associated with the formation of an engineering-sized crack and a region consisting of the growth of this crack up to component failure. One category relates to the cycling life for the formation of a fatigue crack in a smooth test specimen, the so-called S-N fatigue properties; (stress versus number of cycles). The second relates to the growth of a pre-existing crack. Laboratory test have shown that LWR coolant water can have a detrimental effect on both S-N fatigue properties and fatigue crack growth. Much lower failure stresses and much shorter failure times can occur in a corrosive environment compared to the situation where the alternating stress is in a non-corrosive environment.

Corrosion fatigue should not be confused with stress corrosion, which is crack initiation and growth under sustained load or residual stress. Corrosion fatigue is a mostly transgranular crack growth phenomenon. The corrosion fatigue fracture is brittle and the transgranular cracks are not branched. The corrosive environment can cause a faster crack growth and/or crack growth at a lower tension level than in dry air. Even relatively mild corrosive atmospheres can reduce the fatigue strength of aluminium structures considerably, down to 75 to 25% of the fatigue strength in dry air. No metal is immune from some reduction of its resistance to cyclic stressing if the metal is in a corrosive environment. Control of corrosion fatigue can be accomplished by either lowering the cyclic stresses or by various corrosion control measures.

Results from laboratory tests generally reveal a detrimental effect of BWR and PWR water environments on the fatigue lives of specimens made from carbon steels, low-alloy steels, austenitic stainless steels and nickel (Ni)-based alloys. The parameters predominantly affecting the fatigue life of laboratory specimens are strain rate, temperature, dissolved oxygen concentration in the water and Sulphur content of the material, the latter of which is only applicable for carbon steels and low alloy steels.

The detrimental effects of reactor environments on fatigue lives have been known for more than 30 years. Reactor coolant pressure boundary components exposed to the reactor water environment have exhibited degradation due to environmentally enhanced fatigue in service. In all these cases, unacceptable component fabrication, material selection, or plant operation (and combinations of these) were identified as root causes leading to the degradation. Significant large-scale, generic degradation due to environmental fatigue has not been observed in service even though environmental effects due to the impact of light water reactor (LWR) coolant were not explicitly considered in current design rules. NRC investigation of the risk associated with corrosion fatigue in the Fatigue Action Plan concluded that there was no inherent risk to core damage frequency for operating nuclear reactors, although increased probability of leakage indicates this issue requires management for extended plant operation [[22] [[23].

Limited observations of cracking due to corrosion fatigue stand in contrast to significant occurrences of stress corrosion cracking in stainless steels and Ni-based alloys, which have been observed more systematically in reactor coolant pressure boundary welds and reactor internals from LWR plant operational experience worldwide.

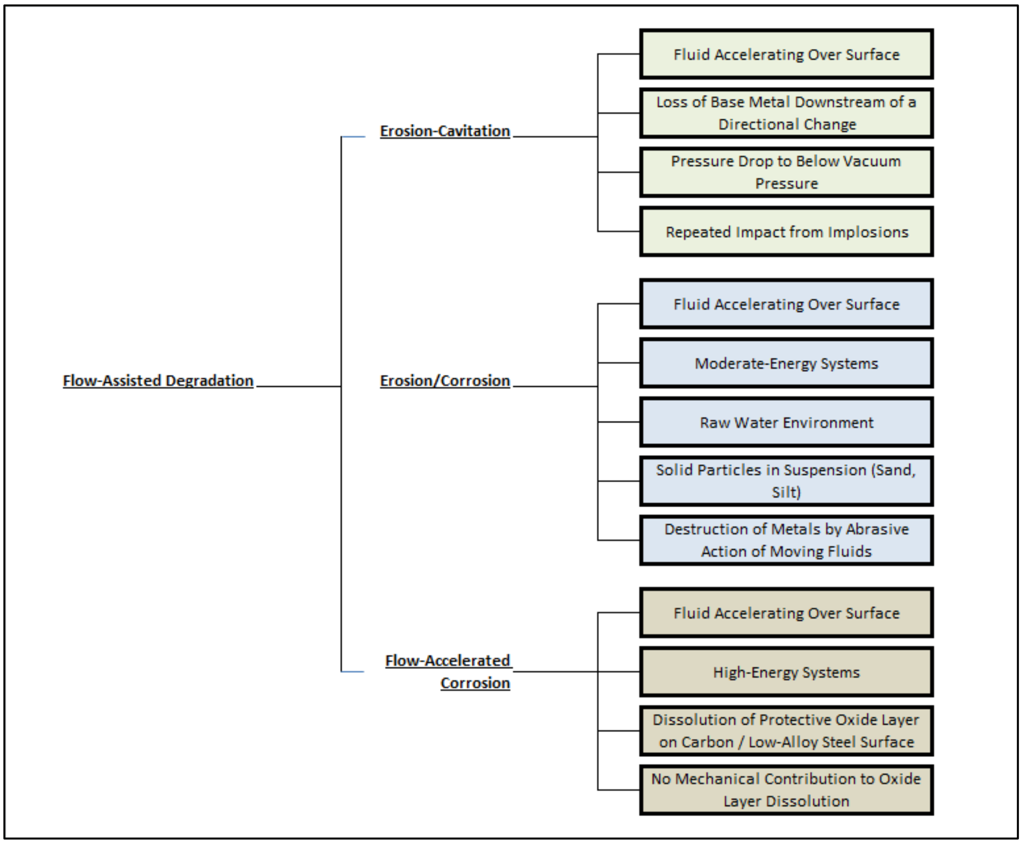
The lack of significant observed degradation in plant components with regard to corrosion fatigue is attributed, at least in part, to the generally conservative design requirements adopted within the ASME code and applicable regulations (e.g. the NRC's requirement to keep the cumulative usage factor less than 0.1 for break exclusion locations). Margins in the design requirements appear to compensate for the detrimental environmental effects.

Another consideration when comparing the environmental effects between laboratory and service components is the applied loading associated with pressure and thermal transients. Laboratory testing typically relies on simple mechanically-controlled loading transients (e.g. artificially shaped waves), and may arguably include some amount of compensation for the effects of more complex thermal transient loading. Additionally, plant components are often subjected to thermal transients with long-lasting hold times at almost constant load or temperature corresponding to steady-state operating conditions which may lead to some strain recovery within the component. These differences may affect fatigue lives.

3.6. Flow-assisted degradation

The term "flow-assisted degradation" (FAD) encompasses several phenomena, all of which result in the degradation of piping through material loss. These phenomena include erosion, erosion-cavitation (E-C), erosion/corrosion (E/C), flow-accelerated corrosion (FAC), and liquid droplet impingement erosion. The distinguishing characteristics of the different FAD-mechanisms are illustrated in Figure 3.15. This figure represents a high-level guidance for event classification and coding.

Figure 3.15. Distinguishing Characteristics of the Different FAD-Mechanisms



3.6.1. Erosion-cavitation

Erosion-cavitation (E-C) is the process of surface deterioration and surface material loss due to the generation of vapour or gas pockets inside the flow of liquid. These pockets are formed due to low pressure well below the saturation vapour pressure of the liquid and erosion caused by the bombardment of vapour bubbles on the surface. Erosion-cavitation usually involves an attack on the surface by gas or vapour bubbles, creating a sudden collapse due to a change in pressure near the surface. Low pressure (below the saturated vapour pressure) is generated hydrodynamically due to various flow parameters, such as liquid viscosity, temperature, pressure and nature of flow. This deterioration is initiated by a sudden surge of bubbles hammering the surface, resulting in deformation, as well as pitting.

3.6.2. Erosion-corrosion & liquid droplet impingement erosion

Erosion-corrosion is a mechanism of material loss by mechanical means due to impingement, abrasion or impact, etc., resulting from the movement of a liquid or gas over the surface of a metal coupled with corrosion. This type of degradation is characterised by attack like small pits with bright surfaces free from corrosion products. These pits often have the form of a horseshoe with the nib pointing in the current direction. Erosion-corrosion may occur where the velocity of liquid is too high. Most exposed are places where there are effects of turbulence, e.g. joints, bends etc. The corrosion rate will accelerate if the liquid contains gas bubbles and/ or solid particles. Systems susceptible to erosion-corrosion include raw water cooling systems; e.g. Circulating Water and Service Water systems.

Liquid droplet impingement (LDI) erosion is a subset of erosion-corrosion. Liquid droplets are often generated in piping that operates in a two-phase flow condition, and is due to the entrainment of liquid water from the upstream and also by the heat transfer through the pipe wall. In the region behind the orifice and the valve in the pipeline, the velocity of the droplets is highly accelerated due to the contraction effect. This results in the occurrence of high impact pressure on the inner surface of the pipe due to the liquid droplet impingement. The impact pressure of the droplets increases as high as several hundred MPa, which is beyond the elastic limit of the pipe-wall material, so that the pipeline is often damaged by the impact pressure of droplets. This phenomenon is called liquid droplet impingement (LDI) erosion. In general, the LDI occurs on the dorsal side (extrados) of a bend or elbow, where the droplets cannot follow the steam flow due to the inertia of the droplets.

3.6.3. Flow-accelerated corrosion

The first CODAP Topical Report [4] provides details on the flow accelerated corrosion (FAC) mechanism. FAC leads to wall thinning (metal loss) of steel piping exposed to flowing water or wet steam. The wall thinning is the result of the dissolution of the normally protective oxide layer formed on the surfaces of carbon and low alloy steel piping. The rate of metal loss depends on a complex interplay of several parameters including water chemistry, material composition, and hydrodynamics, but based on operating experience the metal loss can be as high as 3 mm/yr. Carbon steel piping components that carry wet steam are especially susceptible to FAC. The most dominant variables are temperature, fluid velocity, fluid pH, the water amine and oxygen content, steam quality, void fraction of the fluid, piping geometry, and the pipe material composition.

3.7. Stress corrosion cracking

Stress corrosion cracking (SCC) or environmentally assisted cracking (EAC) is mainly observed in the weld deposit and heat affected zone and it is considered that it occurs due to synergistic effect of three factors of material, stress and environments. SCC may occur when a susceptible material is subjected to stress in a corrosive environment. One example of a scenario that might lead to SCC is one in which a weldment is (1) sensitised due to high heat input, (2) subjected to high local stresses such as welding residual stresses, and (3) the weldment is subjected to a corrosive environment. There are five types of SCC mechanisms:

- intergranular SCC (IGSCC) of stainless steel;
- IGSCC of nickel-base alloys, typically referred to as primary water SCC (PWSCC);
- irradiation assisted SCC (IASCC) of stainless steel;
- transgranular SCC (TGSCC), including external chloride-induced SCC (ECSCC) of stainless steel;
- strain induced SCC (SICC) of high-strength carbon steel.

3.7.1. Intergranular stress corrosion cracking

Intergranular Stress Corrosion Cracking (IGSCC) of stainless steels is a time dependent type of ageing phenomenon. The IGSCC morphology is associated with the temperature/time fabrication conditions that gave rise to thermal sensitisation and the formation of chromium carbide precipitation (e.g. $M_{23}C_6$) and chromium depletion at the grain boundary. The reduction in chromium concentration adjacent to the grain boundary gives rise to a reduction in passivity and makes the material susceptible to intergranular stress corrosion cracking.

Since the late 1970s the importance of water purity control became increasingly apparent, especially with regard to creviced components (where the geometry and oxidising conditions in the bulk environment could give rise to increased anionic activity in the creviced region), even though the bulk water purity was acceptable at that time. This water purity aspect was of importance for environmentally assisted cracking of stainless steel, low alloy pressure vessel steels and nickel-base alloys.

Subsequent to the introduction of low carbon and stabilised grades of stainless steel, IGSCC has occurred in these materials that were clearly not in a sensitised condition. It has been shown that their susceptibility to IGSCC is due to cold work induced during fabrication. In many cases the initial cracking was found to be initially transgranular then changing to an intergranular cracking mode. The initial transgranular cracking is often associated with a surface layer of cold work induced by grinding.

Failures have also occurred where IGSCC is attributed to the presence of either severe bulk cold-worked material (cold bent piping). The mechanism by which cold work renders austenitic alloys susceptible to IGSCC in BWR environments is not fully understood and is still being investigated. It is possible that there is an unfavourable interaction between deformation-induced martensite, high residual stresses and strains, and localised deformation.

3.7.2. Primary water SCC

Alloy 600 (Inconel™ 600), a nickel-base metal, was developed in the 1950s for use as a construction material for nuclear power plants. The material was qualified for use in nuclear power plants because of its perceived resistance to SCC; it was viewed as an alternative to Type 304 or Type 316 austenitic stainless steels. An early (possibly the earliest) recorded instance of SCC of Alloy 600 material is that of the failed inspection tubes in the Swedish Ågesta Reactor[11] in September 1964 [24]. According to Reference [25], the materials research in the early 1960s concluded that nickel-base materials with high nickel content (> 72%) to be resistant to SCC in chloride and alkaline environments. The Alloy 600 material was subsequently qualified as structural material for use in PWR plants. A first Alloy 600 failure in a commercial nuclear power plant occurred in July 1972[12] when the German plant KWO Obrigheim[13] experienced a steam generator tube through-wall leak attributed to SCC. Due to the SCC failures of Alloy 600 in direct connection with primary water, many PWR and BWR owners have

11. A combined district heating and power reactor sited below-ground near Stockholm, Sweden. The reactor was permanently shut down in 1974.

12. Der Bundesminister des Innern, Besondere Vorfälle in Kernkraftwerken in der Bundesrepublik Deutschland, Berichtzeitraum 1965-1976, Bonn, Germany, 1977.

13. A small 2-loop PWR commissioned in 1969 and permanently shut down in 2005.

replaced it with alternate materials such as Alloy 690, a higher nickel based alloy, or Alloy 800, an iron based alloy. CANDU users now prefer Alloy 800NG.

Nickel base alloys (e.g. Alloy 600, and corresponding weld metals Alloy 82, 132 and 182), have proved to be generically susceptible to IGSCC in normal specification PWR primary water systems (PWSCC). Recent operational experience shows that the fabrication induced residual stresses have a large influence on PWSCC in alloy 600 weld metal. Examples of components affected include pressuriser, hot leg, cold leg, drain, and reactor coolant pump nozzle-to-safe end dissimilar metal welds, penetrations welded to the reactor vessel and reactor vessel head and steam generator.

PWSCC in the weld metal grows along the grain boundaries of columnar crystal dendrite packets. Initiation in the weld metal is often thought to be the result of typical and non-typical fabrication processes leading to locally high residual stresses, or surface stresses from, for example, grinding. To date it has been found that the susceptibility to SCC of nickel-based alloy weld metal is higher than that of the base metal. IGSCC of ni-base alloys in BWRs is believed to be attributed to Cr depletion at grain boundaries, similar to IGSCC in thermally sensitised stainless steels.

3.7.3. Irradiation assisted SCC

Irradiation assisted stress corrosion cracking (IASCC) is essentially a time dependent type of ageing phenomena characterised by the threshold of irradiation level related to susceptibility of IASCC. There are increasing concerns that it might occur in the high fluence region if no countermeasures could be conducted. IASCC requires stress, aggressive environment and a susceptible material. However, in the case of IASCC, a normally non-susceptible material can be rendered susceptible by the accumulation of neutron irradiation and has highly time dependency compared to the other SCC mechanisms.

IASCC is therefore an ageing mechanism that affects reactor vessel internals in both BWR and PWR plants. Neutron irradiation effects are primarily thermal but, in the case of gamma heating of thick section, the higher temperatures generated can have a significant effect on void swelling. In addition, neutron capture reactions induce transmutation reactions and hence changes in chemical composition of the material. Irradiation hardening and radiation induced segregation (RIS), due to chromium depletion and silicon enrichment at grain boundaries, are considered to be the most probable factors leading to IASCC susceptibility.

3.7.4. Transgranular stress corrosion cracking

The earliest indications of cracking in unirradiated austenitic stainless steels occurred in the late 1960s in components where the temperature was $<100^{O}$C and this was observed during storage and fabrication, and operation. The degradation mode was transgranular stress corrosion cracking (TGSCC) on the outside surface of the pipe. This failure mode was exacerbated by (a) chloride contamination from humid marine environments or from insulation, and (b) the dissolved oxygen (air) in the water or condensate. These cracking incidents were effectively managed by appropriate control of the chloride contamination and by taking into account the beneficial effect of soluble silicate originating from the glass fiber insulation (USNRC, 1973)[14].

As with other types of SCC, TGSCC requires stress, an aggressive environment and a susceptible material. In addition, it requires the presence of chloride contamination or other halide anions such as fluorides, and may occur even in materials in the solution heat treated condition. It is generally a problem that initiates on the outside surfaces of components mainly due to lack of attention to adequate cleanliness (also known as external chloride stress corrosion cracking).

TGSCC has also occurred from inner surfaces, mainly in pipe sections containing stagnant two phase coolant, where evaporation and concentration of chlorides can occur. Wetting due to condensation or nearby water leaks allows an aqueous environment to form that leads to TGSCC, usually accompanied by pitting or crevice corrosion. The stress required for chloride induced TGSCC is relatively modest, the threshold being close to the proportional yield strength of solution annealed austenitic stainless steels. Implementation of the known adequate procedures to ensure appropriate surface cleanliness is a continuing necessity that requires careful management attention at all stages of construction and operation of nuclear power plants. External chloride stress corrosion cracking (ECSCC) is TGSCC initiated on the outside surface of a component due to the presence of chloride in sea salt, coatings, etc. attached to the material surfaces and by perspiration.

3.7.5. Strain induced corrosion cracking

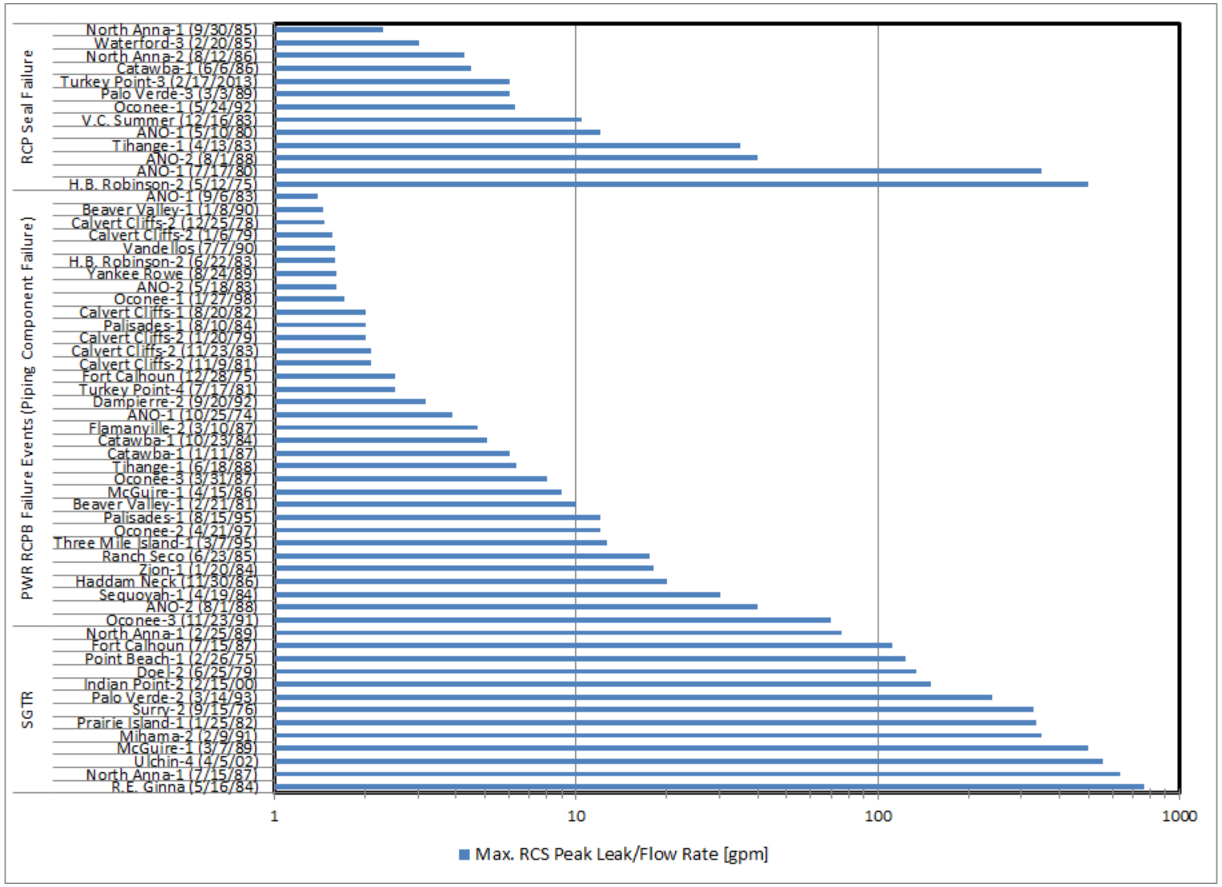
Strain induced corrosion cracking (SICC) [26] is used to refer to those corrosion situations in which the presence of localised dynamic straining is essential for crack formation to occur, but in which cyclic loading is either absent or restricted to a very low number of infrequent events. SICC has been observed in pressurised components in German NPPs made of higher-strength ferritic carbon steel. This kind of degradation has caused circumferential cracking in feed water nozzle regions and at welds and axial cracking in pipe bends but also in straight sections of thin-walled piping in German BWRs.

3.8. High-level database summary

Examples of the CODAP event database content is summarised in Figures 3.16 through Figure 3.19. Figure 3.16 is a summary of significant PWR reactor coolant system (RCS) leak events and includes piping and non-piping RCS components. Figure 3.17 is an overview of the database content by degradation mechanism. Figure 3.18 shows the degradation mechanism propensity normalised against IGSCC in a non-mitigated BWR operating environment. Limited to RCS piping, Figure 3.19 is a summary of the PWSCC operating experience.

14. Note that the potential substitution of fibrous silicate insulation with mineral wool insulation (an action that would minimise the clogging of sump pump filters during a severe accident) would reintroduce the danger of chloride-induced TGSCC of stainless steel piping since the beneficial effect of silicates would be removed.

Figure 3.16. Summary of Significant PWR Reactor Coolant System Leak Events[15]



15. In Figure 3.16 OE data on RCP seal failures or steam generator tube failures (SGTR) are included for reference only. CODAP does not collect data on these event types.

Figure 3.17. Database Content by Damage / Degradation Mechanism

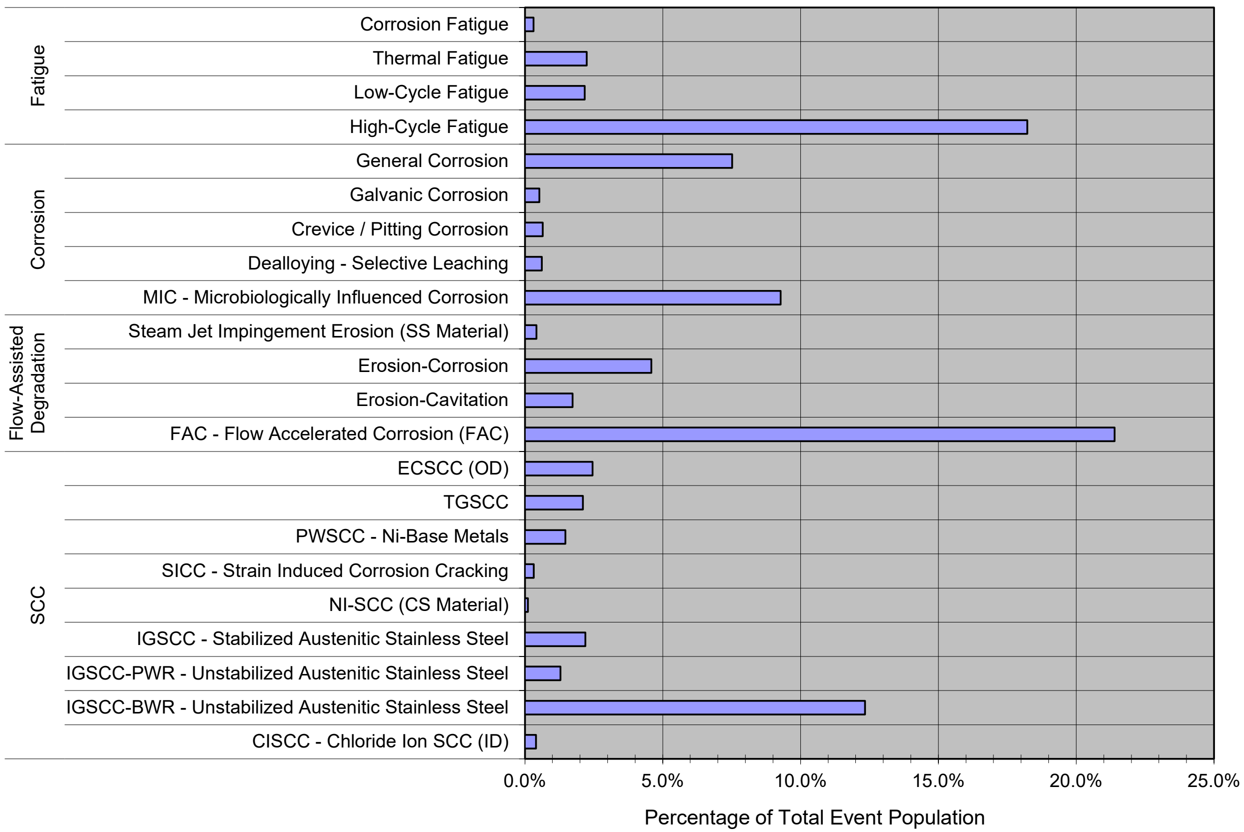


Figure 3.18. Normalised Piping Degradation Propensity

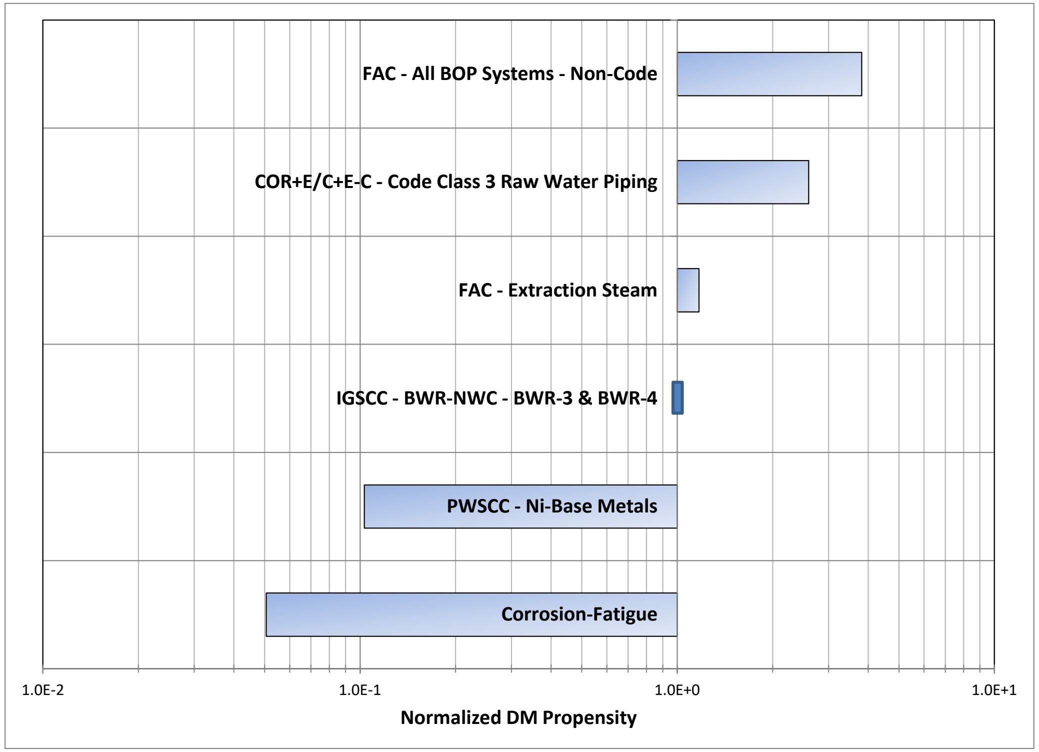
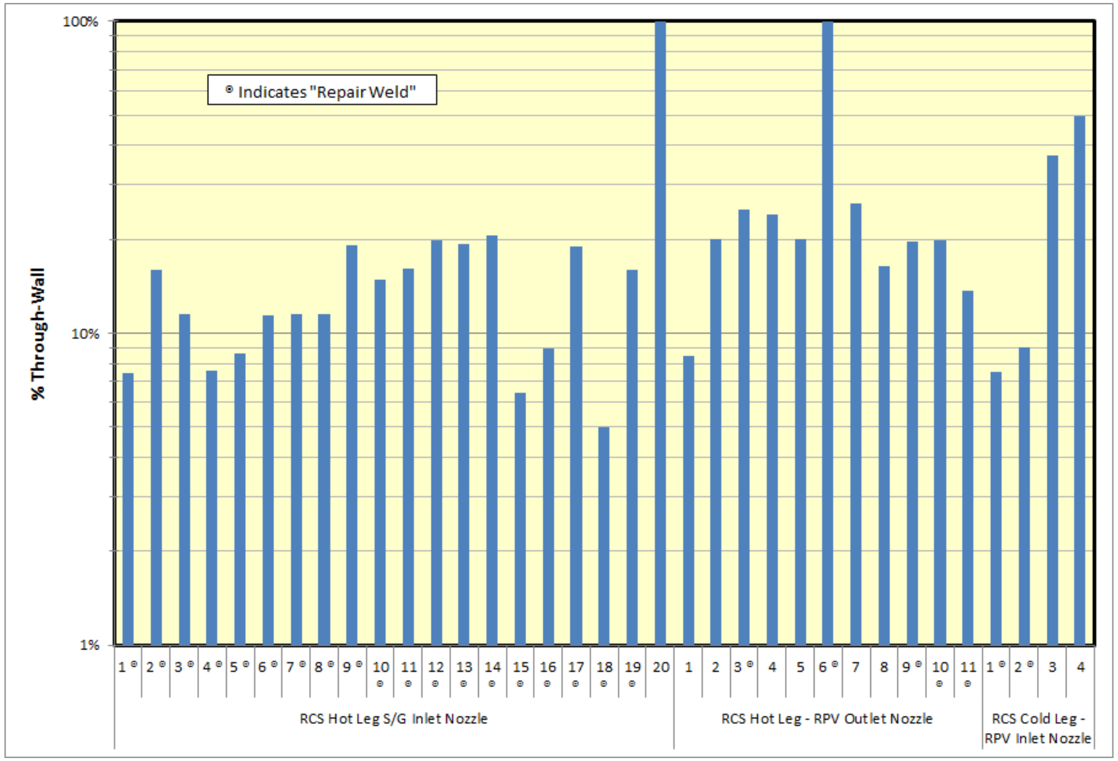


Figure 3.19. Selected PWSCC Operating Experience by Location of Degraded / Failed Component[16]



16. Superscript ® indicates a repair weld. This chart is a summary of specific PWSCC events. As one example, to date there have been 20 events (one through 20) involving PWSCC in Reactor Coolant System Hot Leg Steam Generator inlet bimetallic welds. Full descriptions are found in the CODAP event database and by using the following query definition: PWR – RCS Hot Leg – Bi-metallic Weld – PWSCC – Crack Depth.

4. CODAP database structure

The CODAP Event Database is a web based, relational SQL 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 second term the CODAP event database included ca. 4,900 records on degraded and failed metallic piping and non-piping passive components. Section 4 presents the scope of the event database and summarises the database structure and main features of the online event database.

4.1. 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 [[27], 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 emphasised 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 specialisations to arrive at a scope definition as summarised in Table 4.1. Consistent with the operating procedures, the scope definition is revisited and periodically updated. In Table 4.1, the column "Metallic, Non-Piping Passive Components" captures the BWR and PWR internals as documented and evaluated in IAEA-TECDOC-1471 [28] and IAEA-TECDOC-1119 [[29], respectively. 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 (General Requirements) [[30] 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.

Table 4.1. Scope of CODAP Event Database[17]

METALLIC PASSIVE COMPONENTS			
PIPING COMPONENTS		NON-PIPING PASSIVE COMPONENTS	
Piping - Below Ground/Concealed		Reactor Pressure Vessel (RPV)	
	Pipe - Concrete Encased Pipe		Vessel Head Penetration - PWR
	'Bonna' Pipe		Bottom Mounted Instrument (BMI) Nozzle - PWR
	Pipe - External Coating		RPV Head Thermocoupling (T/C) Housing - PWR
Ex-RPV - In-Plant Piping (Accessible)			RPV Head T/C Nozzle - PWR
	Pipe - Base Metal	Pressurizer	
	Pipe - Cement Lined		Pressurizer Heater
	Pipe - Epoxy Lined		Pressurizer Manway Diaphragm Plate
	Pipe - Rubber Lined		Pressurizer Nozzle
	Bend		Pressurizer Relief/Safety Valve Nozzle
	Blind Flange	RPV Internals	
	Branch-Connection - Socket Welded		Baffle-Former Assembly Bolt - PWR
	Branch-Connection - Stub-in Weld		Core Shroud Access Hole Cover Weld
	Cap/End-Cap		Core Shroud Head Bolt - BWR
	Elbow		Core Shroud Weld - BWR
	Elbow - Long-Radius		Core Shroud Tie Rod - BWR
	Elbow - 45-Degree		Core Shroud Support - BWR
	Elbow - 90-Degree		Core Spray Sparger - BWR
	Expander		In-Core Instrument Tube
	Expansion Joint		Jet Pump Hold-Down Beam
	Fitting		Jet Pump Riser
	Mixing Tee		Jet Pump Support Brace
	Reducer		Steam Dryer - BWR
	Socket Weld	Pump	
	Tee		Pump Casing
	Weld - Butt Weld		RCP Turning Vane Bolt
	Weld - Dissimilar Metal Weld	Valve	
	Weld - Girth Weld (Full Penetration Weld)		Valve Body
	Weld		

17. Corresponds to drop-down menus, and as currently implemented there is no navigation tool associated with these drop-down menus

4.2. Database submissions

Respective National Coordinator is responsible for data submissions. The preferred method for submitting new data to the database is via the web-based interface. Data submissions may also be handled by e-mail with event information attached in Microsoft Access, Excel or Word file format. New event information collected by the operating agent on its own initiative will be included in an Excel file marked “possible new event” and sent to the appropriate national coordinator for further consideration. After validation, the national coordinator assumes responsibility for formal data submission and maintenance of the national data sets.

4.3. Database user instructions

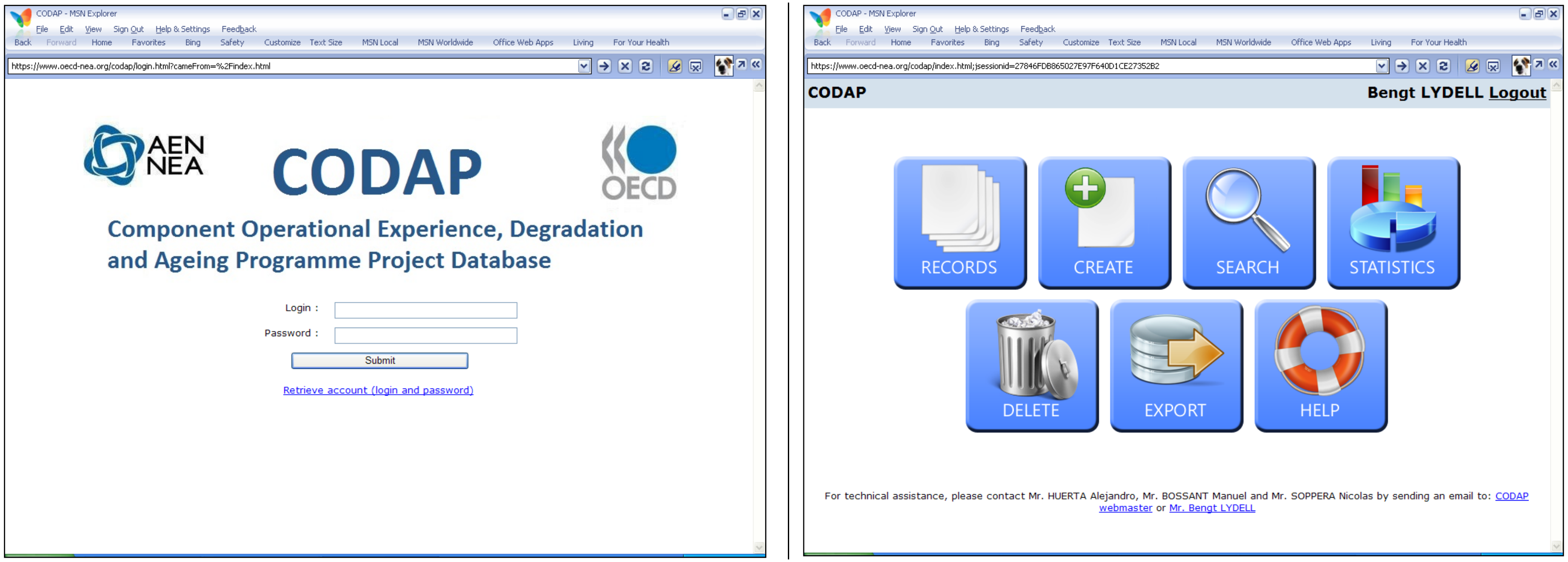
In CODAP the data entry is managed via input forms, tables, roll down menus and database relationships. The CODAP online opening screen and main work area screen are displayed in Figure 4.1. The online version is accessible via a secure server at the Nuclear Energy Agency headquarters. User names and passwords are provided by NEA IT-Department upon written request by a national coordinator. The online version includes help menus. In case of need for additional assistance, please contact the NEA secretariat, NEA-IT and/or the operating agent. The project members work area includes a FAQ area. Request for new key words to be added to drop-down menus should be sent to the operating agent.

Consistent with the CODAP security levels, the work flow area of the event database facilitates records management including the review and approval of individual failure records. A single data entry form is used to input failure data. Four data management commands are included at the bottom of the data entry form; Figure 4.2. Upon completion of data entry the user will go to the workflow area; Figure 4.3. A record may be marked as “draft” if additional technical details are to be added. When a record is ready for review the corresponding command is invoked and an e-mail is automatically sent from the “operator” to the “national coordinator” (NC) prompting the review process. When a record is ready for QA by the CODAP Operating Agent (CODAP-OA) the corresponding command is invoked and an e-mail alert is automatically sent from the NC to the CODAP-OA with a prompt for final review. In case corrective action is required, the CODAP-OA returns the data record to the NC for comment resolution. Upon completion of the review process the CODAP-OA marks the record as “approved.” In summary:

- CANCEL. If a record is entered in error, pressing “cancel” deletes information added from the database.
- WORKFLOW. When action is needed (e.g. review or approval), pressing “Workflow” switches screen from data entry mode to workflow area (Figure 4.3).
- SAVE. Whenever data entry is interrupted, pressing the “save” button allows for continuation of data entry at another time.
- FINISH. This is shortcut and returns data entry process to next level. As an example, if data is uploaded by the OA, pressing “finish” returns status to “approved.” If data is uploaded by an operator, pressing the “Finish” returns status to “Ready NC Review.”

- DRAFT. This indicates work-in-process, and that an operator is in the process of filling out the data entry form. There is no other action pending.
- READY FOR REVIEW BY NATIONAL COORDINATOR. Pressing this button results in an e-mail notification to the National Coordinator(s) on record. Data validation is requested.
- READY FOR QA. Pressing this button results in an e-mail notification to the Operating Agent. Upon final review, additional action by the national coordinator(s) on record may be requested, or, the record is approved.
- RETURN FOR REVIEW. Pressing this button results in an e-mail notification to the national coordinator(s) on record. Additional data validation is requested.

Figure 4.1. CODAP Online Opening Screen & Main Work Area Screen[18]



18. The "HELP" area includes an abbreviated version of the coding guideline.

Figure 4.2. CODAP Data Entry Form

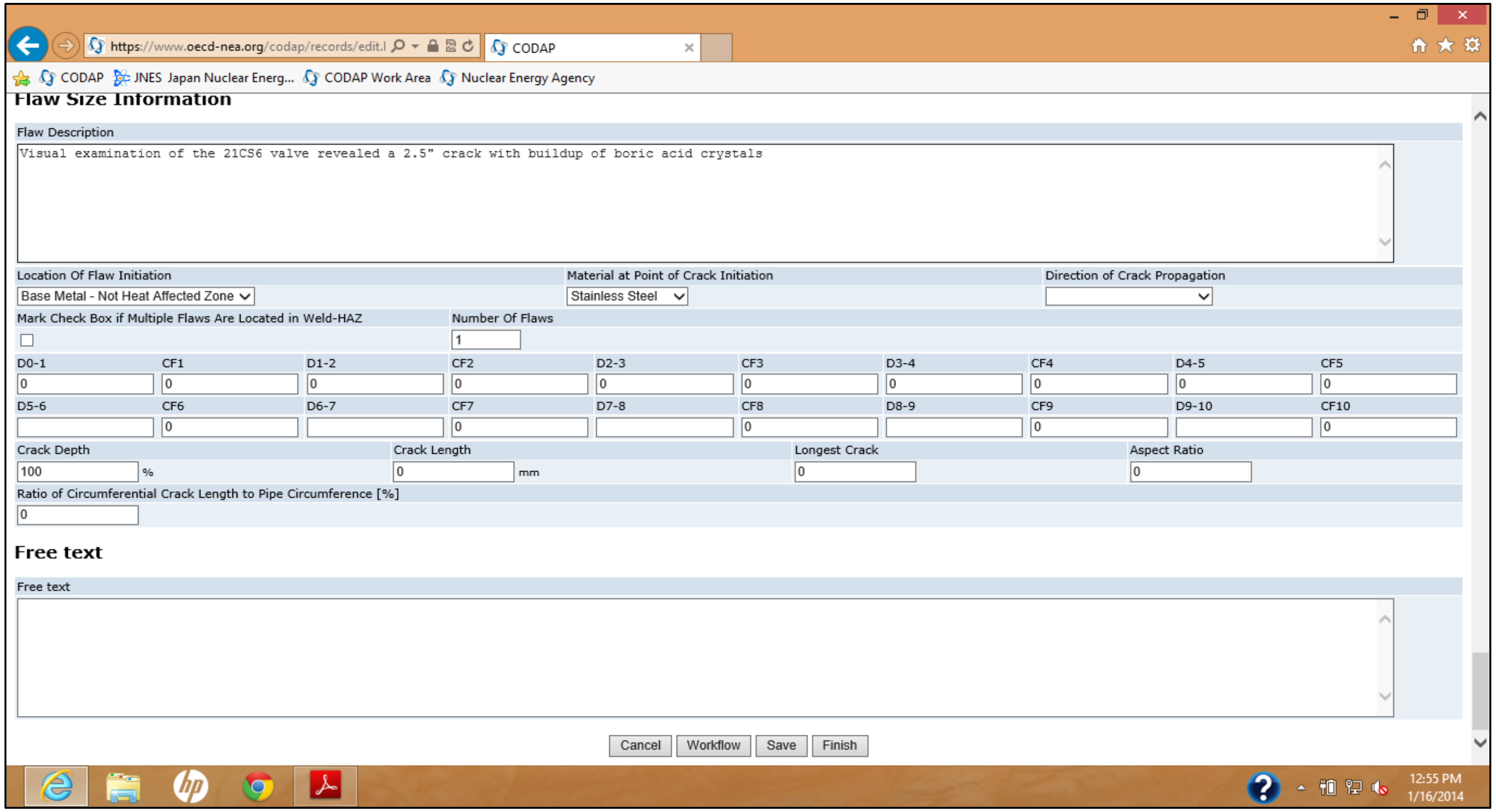
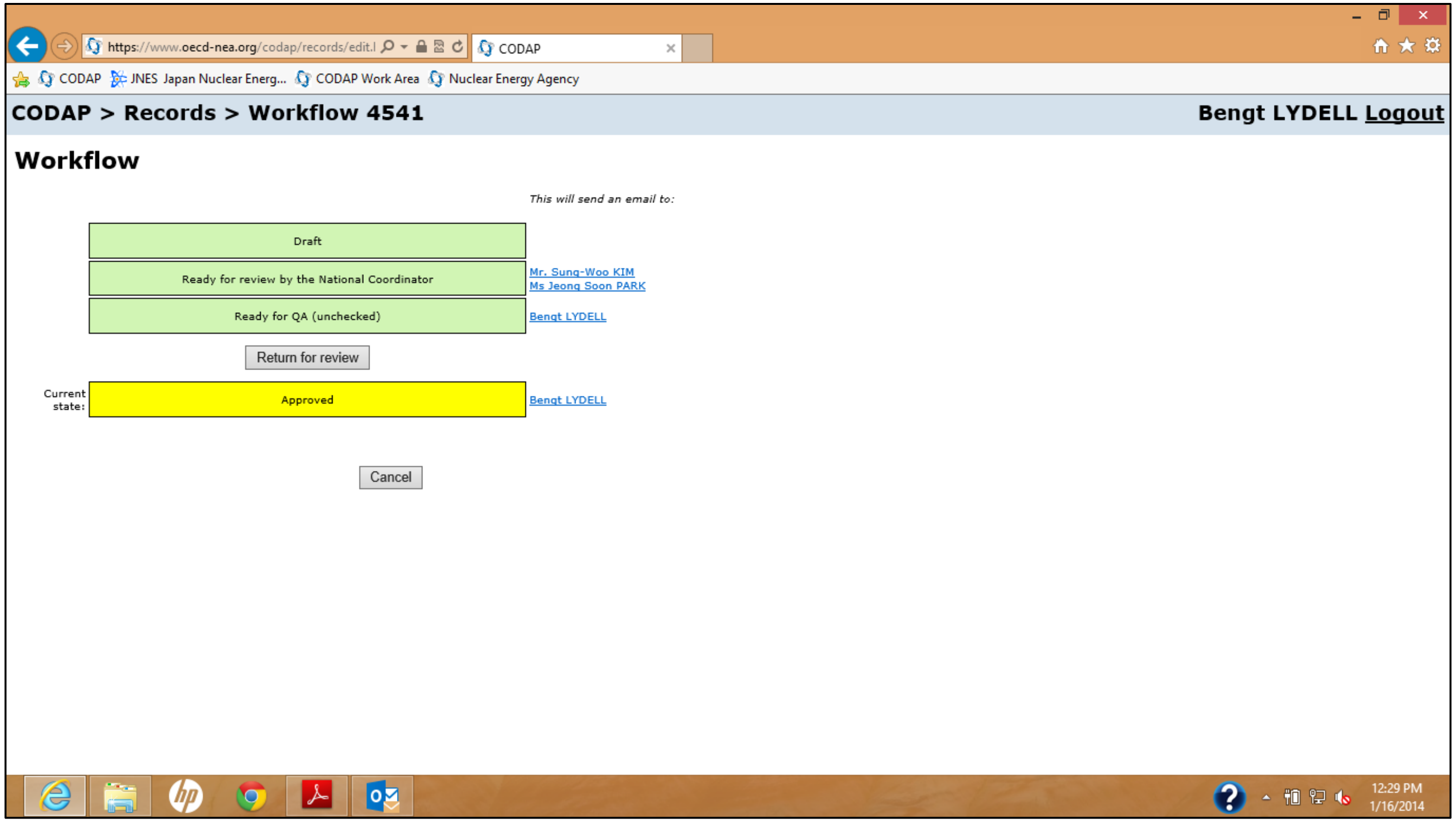


Figure 4.3. CODAP Data Entry Form & Work Flow Area



4.4. Database field categories

It is intended that each CODAP database record provides a complete and unambiguous description of a specific passive component degradation or failure. Not only shall a selected database record withstand an independent review for technical accuracy and completeness, it shall also be fit-for-application, either by direct or indirect database application. A direct database application implies that query results can be directly inputted to a calculation. By contrast, an indirect application implies that additional data processing is required to prepare input as specified by a stand-alone application programme. Irrespective of intended application, database users shall have full confidence in passive component failure event interpretations and classifications. Additionally, users should be able to perform data reinterpretations or reclassifications to support new application requirements without having to retrieve additional source data for the database records of interest.

4.5. Data entry

Currently, the CODAP database structure consists of a single data entry form. The data entry form is organised to capture essential passive component failure information together with supporting information. The data entry form consists of four areas[19]:

1. General failure data. This area represents the minimum required information (Figure 4.5).
2. Flaw size information. This area is for recording flaw size (depth, length, aspect ratio) and orientation (Figure 4.6).
3. In-service inspection (ISI) history. This area is used to record any relevant information about ISI performed in the past (e.g., date of most recent inspection). Also documented here is information regarding ISI program weaknesses or failures (Figure 4.7).
4. Root cause information. This area records factors or conditions contributing to a degraded condition. Also included in this area is a field for free-format comments on corrective actions, or other information of relevance to a specific event (Figure 4.8).

The database is built around event narratives. The screening and classification of each database record is based on the detailed event narratives. A typical event report includes the following information:

- Flaw description. This includes details on the date of a discovery, plant operational state, description of how the flaw was detected, plus a summary of the preliminary evaluation of the type and extent of the flaw (e.g. a non-through-wall crack or a small through-wall leakage) and the direct (e.g. a reactor trip) or indirect impact on plant operation.
- Non-piping passive component & piping component details. Details on the exact location of the flaw, with a description of component dimensions, code class,

19. For illustrative purposes, the data entry illustrations are from the Microsoft® Access version of the database. The current version of the online database uses a single input form. The online version is currently undergoing a significant program update in which the input format will be revised. The new online version is scheduled for release in the first quarter 2018.

material and wall thickness (of piping), flaw size, operating temperature and pressure and/or design temperature and pressure.

- Root cause determination. A root cause determination involves an evaluation of NDE results, sometimes in combination with a destructive examination followed by more detailed metallographic examination. The root cause determination focuses on the identification of underlying causes of a degradation or failure.

Figure 4.4. Event Description – Basic Information

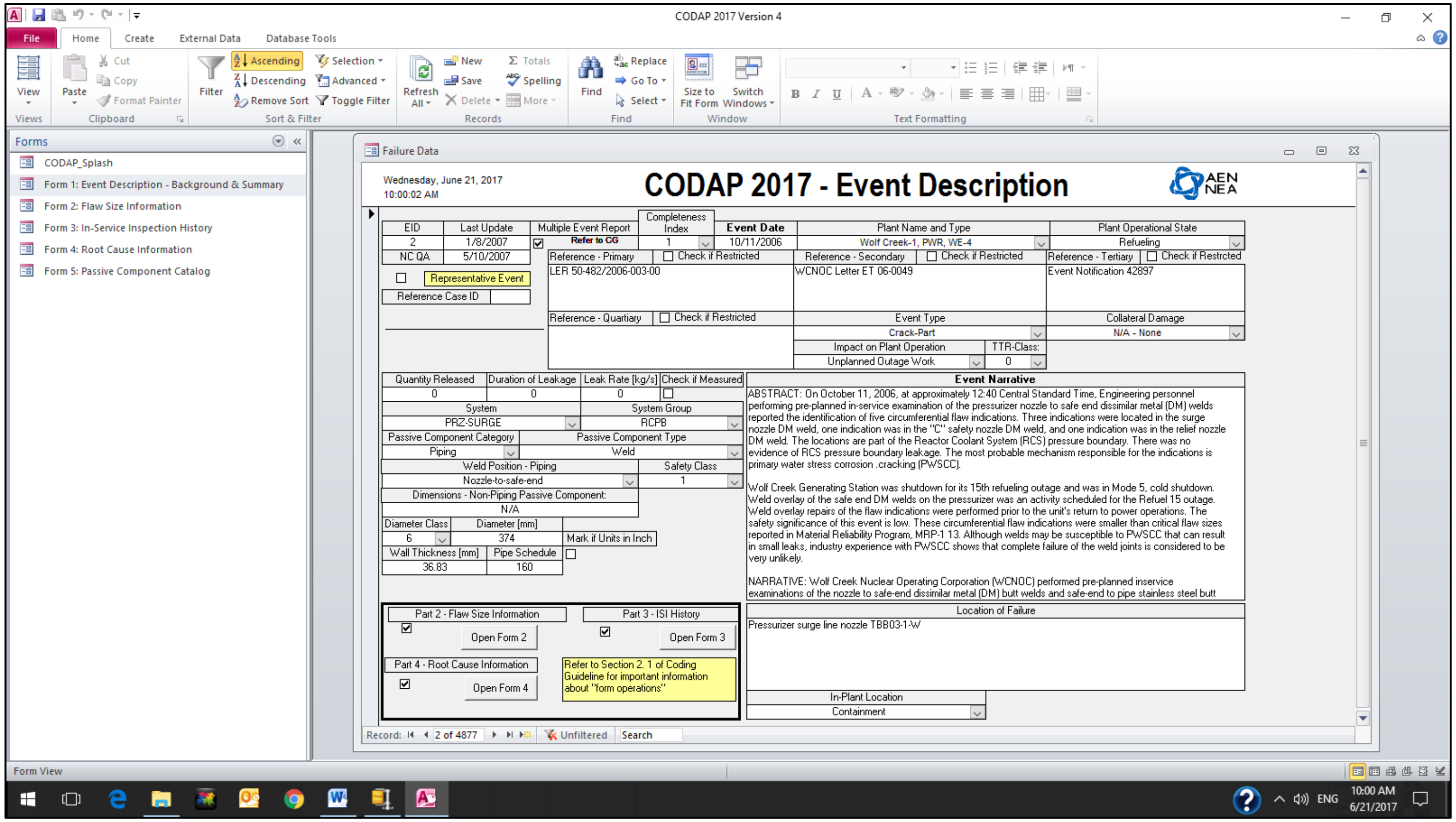


Figure 4.5. Flaw Size Information

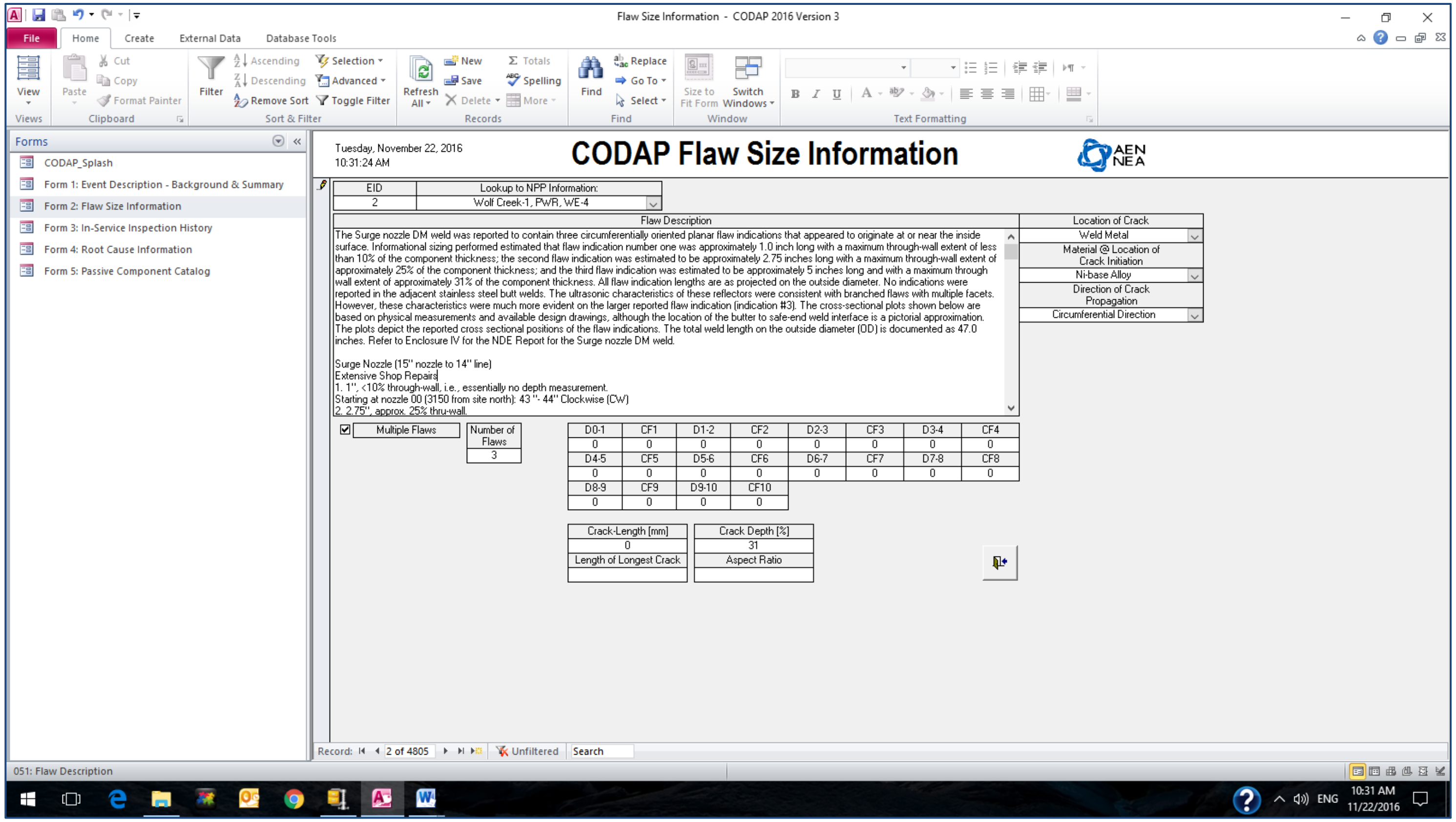


Figure 4.6. In-Service Inspection History

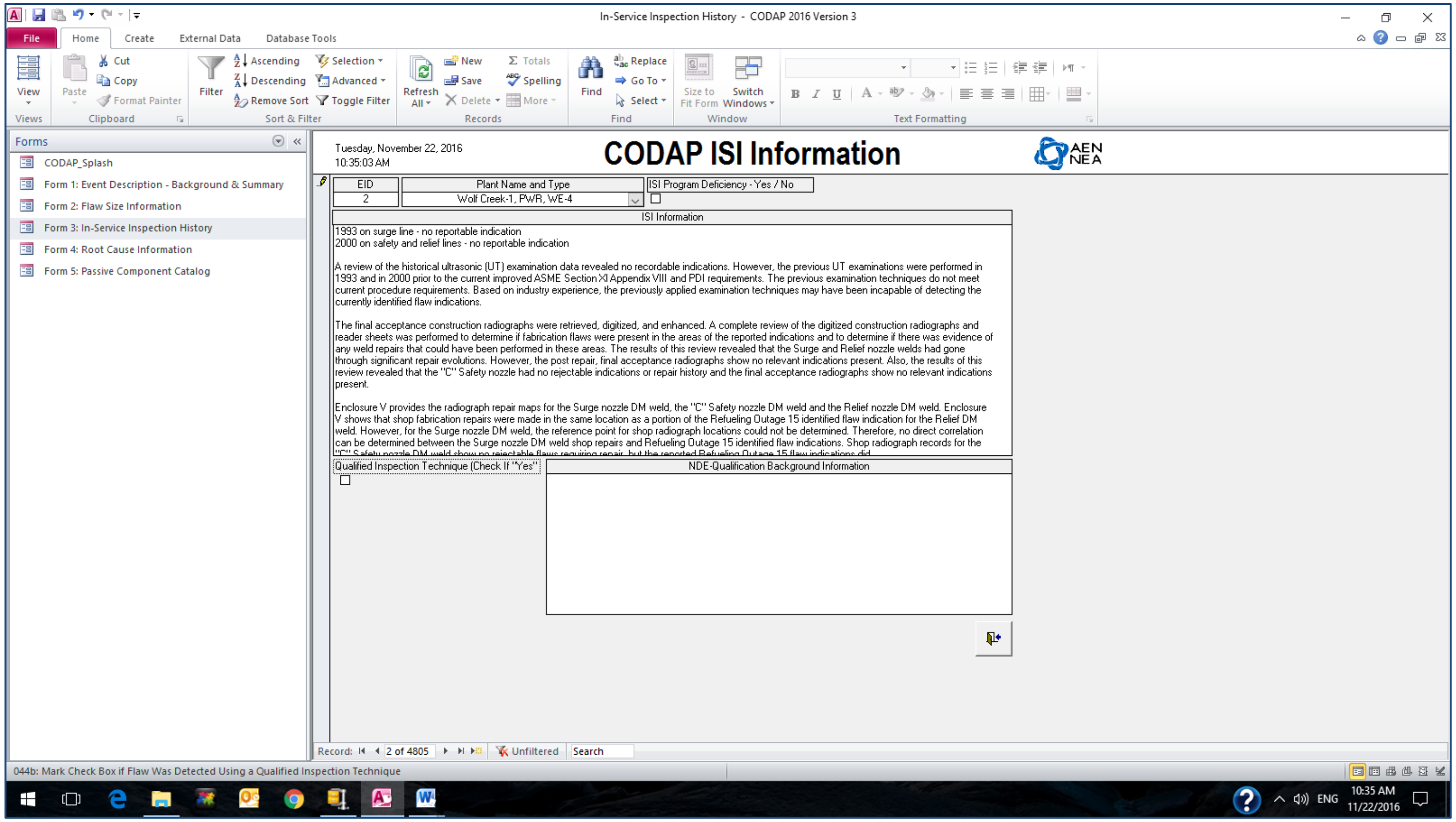
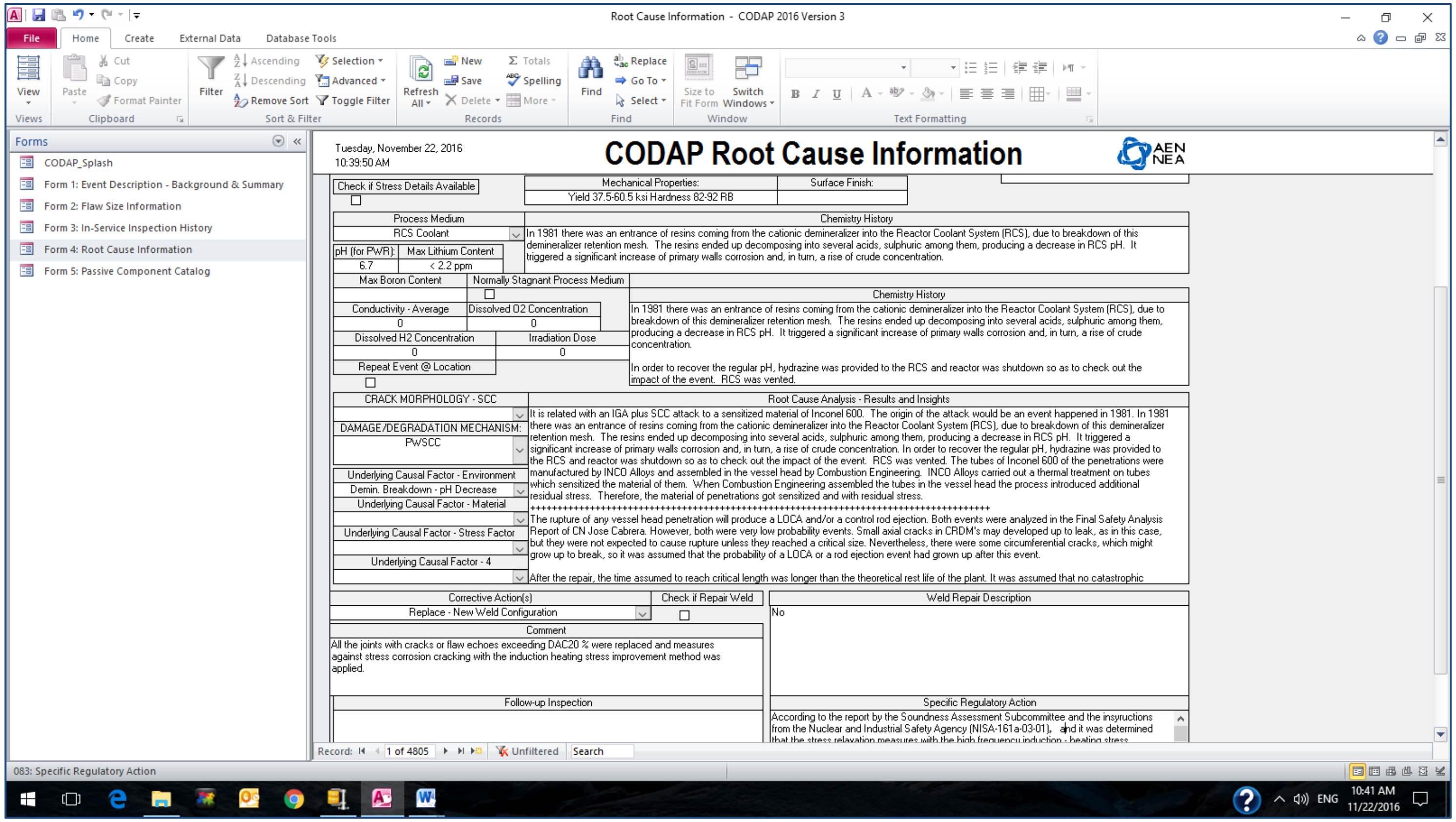


Figure 4.7. Root Cause Analysis Information (Partial Screenshot)



- Results of Augmented ISI. Each country has national guidelines and requirements for augmented inspections given the detection of a flaw. As one example, the U.S. NRC Generic Letter 90-05 (Guidance for performing temporary non-code repair of ASME code class one, two and three piping; 15 June 1990) states:
  - When a flaw has been evaluated and found acceptable (for continued operation using a temporary repair), the plant owner should perform an augmented inspection to assess the overall degradation of the affected system. The augmented inspection, performed within 15 days of detection of the flaw, which results in a temporary non-code repair, is a part of the relief acceptance criteria of the temporary non-code repair of code class three piping.
  - From the root cause determination, the most susceptible locations should be identified. The extent of the augmented inspection depends on whether the line is high energy or moderate energy. The failure of a high-energy line may have more severe consequences than the failure of a moderate energy line because of the energy content. Thus, a more extensive augmented inspection should be performed for high-energy lines.
  - The inspection of at least ten most susceptible (and accessible) locations for high energy lines and at least five most susceptible (and accessible) locations for moderate energy lines should be performed.
  - Flaws detected in the augmented inspection should be characterised and evaluated. A review of an augmented inspection report could reveal additional flaws that result in new database records.
  - Description of the repair. Details on the type of repair (e.g. weld overlay repair, application of a mechanical clamp, replacement in kind or replacement using different material and or design).
  - Safety significance. The safety significance is based on observed impact (e.g. leak duration, leak rate, range of water/steam jet, spraying/wetting of safety equipment, collateral damage) and/or engineering evaluations, as well as failure potential within or beyond design envelope.

Classifying event reports is oftentimes tedious and time-consuming and can involve reviews of large volumes of documentation. This is especially so where an initial discovery of a flaw results in augmented inspections and the discovery of additional flaws in locations adjacent to the initial discovery, or similar locations but in other piping system trains. Once the reporting has been completed by a plant owner/operator a single set of documents may include detailed technical information on multiple flaws, where each flaw relates to a uniquely defined component boundary definition. As an example, plant through-wall flaws were found in emergency core cooling system (ECCS) piping and a condition report (CR-99-0445) was issued after the discovery of through-wall leaks on both ECCS pipe trains (DN600 piping) within the refuelling water tank pipe trench. Initially a single database record was created. The ECCS walk-down inspection and initial visual examination yielded additional details:

- “A” pipe header. Dry, white boric acid crystals on the upper right fillet weld that attaches the code name plate to the piping spool, approximately 13 mm long crack. Some “weepage” after plate was removed and area cleaned.

- "B" header. Dry, white boric acid crystals on lower south east lug fillet weld adjacent to the pipe clamp for support #2407-17, approximately six mm in diameter. No active leakage.
- "B" header. Dry, white boric acid crystals on upper north-west lug for support #2407-17, adjacent to the lug fillet weld, less than 6 mm in diameter. No active leakage. Linear indication approximately 13 mm long.
- "B" header. Dry, white boric acid crystals found on a support member just below support 2407-19. No active leakage (no evidence of leakage or boric acid on the piping could be found).

Based on the above, the initial database record was modified to address the discovery of "weepage" on the "A" header. Following the initial discovery the following technical information was obtained:

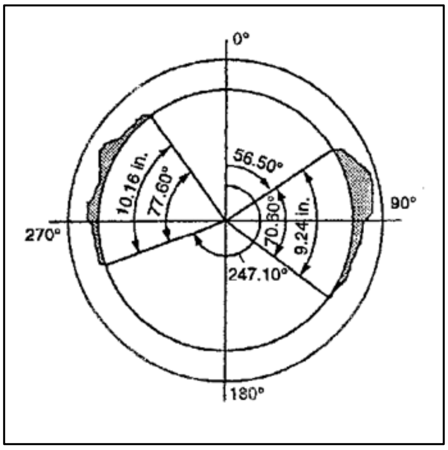
- L-99-90 (Augmented Inspections dated 7 April 1999) with the attachment PSL-ENG-SEMS-98-102.
- Calculation No. AES-C-3566-1 (Evaluation of Corrosion Degradation of 24-inch ECCS Piping at St. Lucie, Unit 2).
- US NRC (24 June 1999): Relief from ASME Code Requirements Related to the Interim Relief Request No. 26 for Emergency Core Cooling System Piping for St. Lucie Plant, unit two.

The report on the augmented inspections provided details on a total of 32 recordable crack indications in the ECCS A- and B-train. Of these indications, two were through-wall flaws adjacent to field welds FW-3 and FW-4, respectively; both located in the train B and two new records were added to the database. Repair of the train A through-wall flaw was completed on 7 April 1999 while repair of the train B flaws was completed on 16 April 1999. In CODAP, all three records have 6 April 1999 as the event date. The "MER Check Box" is check-marked for the three records to ensure that a future database user is made aware of the fact that the flaw discoveries are related.

4.6. Non-through-wall flaw characterisation in CODAP

The flaw characterisation area of the OE data input form consists of 34 fields. Use "enter key" or "arrow keys" to move from one field to another. The data entry requirements are defined below:

- Flaw Description is a free-format memo field. For through-wall flaws, information about size (e.g. equivalent diameter) is included in this field. For part through-wall flaws, this field includes information on flaw depth (a) and length (l), and orientation. For multiple flaws, the number of flaws and their lengths are recorded in the designated fields.



- Check if multiple circumferential flaws (in weld or weld-HAZ).
- nCF (number of circumferential flaws) is the total number of flaws in an affected weld.
- D#-## is the distance, in [mm], between adjacent circumferential flaws. For example, D0-1 is the distance from the zero-degree position (top dead centre for a horizontal pipe per crack profile in the

figure) to flaw #1, and D2-3 is the distance between flaw #2 and flaw #3, etc. A blank field indicates that no information on the spacing is available. (for a vertical pipe, the zero-degree position must be clearly defined).

- CF-# is the length of circumferential flaw “#” [mm]. The flaw number is relative to the 0-degree position; CF-1 is the first circumferential flaw from the reference position.
- Crack Depth [%] is the ratio of crack depth to pipe wall thickness.
- nAF (number of axial flaws) is the total number of axial flaws in an affected area.
- Axial length [mm]: this field relates to the flaw description.
- Ratio of crack length to circumference (relative to the inside pipe circumference.
- Aspect ratio. The ratio of the crack depth to the total crack length.

5. Database application facilities

The CODAP event database is an internet based (or online) relational (SQL) database. In its present form the online version facilitates data submissions, various search and sort functions, and database interrogation functions. The latter are performed in the "Statistics" area of the database. This section of the report addresses the four application facilities: 1) Records Management, 2) SEARCH, 3) Database Query Function, and 4) Export Function. The export function of the Online Version of CODAP produces a XML-file[20] that can be converted to Access or Excel format for further data processing and analysis.

5.1. Records management

The RECORDS tab includes a listing of all data base records. In its current format, the database content can be sorted by "Status" (i.e. "Draft," "Ready for Review by NC," "Ready for QA," or "Approved"), Country, Plant Name, and/or Year of Event. Figure 5.1 shows the results of a data sort by country (the United States) and the calendar year (2017) that an event occurred.

5.2. Search function

The SEARCH tab includes two areas: 1) Search criteria, and 2) Result column. To demonstrate the SEARCH tab functionality, a search is made for all records that address PWSCC. This is done as follows. In the criteria field, select the event database field "Damage/Degradation mechanism." Next, add a search criterion and select "PWSCC." The programme returns a total of 362 records. Using the "Result Column," a sort is made by country, event date, event type and system. Placing the cursor on the "Event Date Column" provides a sort in ascending or descending order. The example in Figure 5.2 shows the earliest recorded PWSCC event to have occurred (or been discovered through in-service inspection) on 27 February 1986.

5.3. Query function

The "STATISTICS" tab supports basic database queries. To demonstrate the "SEARCH" tab functionality, a search is made for failures that are attributed to ECSCC. In the criteria field, select "Damage/Degradation mechanism" and add the criteria "ECSCC." Next, under "Field" select "Diameter Class [mm]." Organised by pipe size, this query returns the number of ECSCC records in database. Since check marks are placed in the "Table" and "Chart" check boxes, tabular and graphic results are displayed once the "Refresh" button is pressed, Figure 5.3. According to this query, the current version of the database includes 155 failure records, of which 14 records address non-

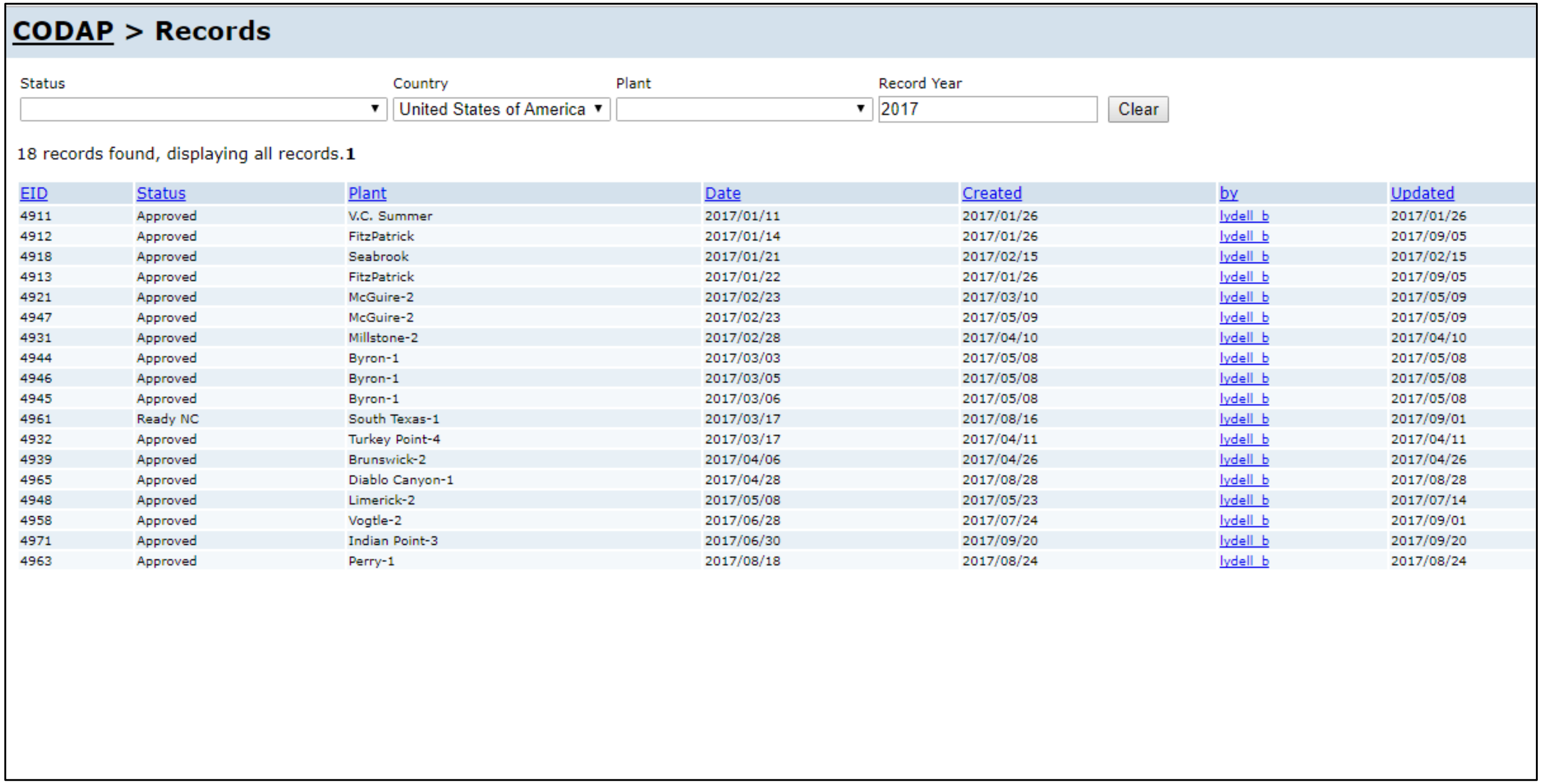
20. XML = Extensible markup language

piping passive components. Further data processing may be performed by exporting the query results as a CSV-file[21] (Figure 5.4). When working within the "STATISTICS" tab:

- Press "Refresh" to launch a database query.
- Press "Finish" to return to "Records."

21. A "comma-separated-values" (CSV) file stores tabular data (numbers and text) in plain text. Files in the CSV-format can be imported to Microsoft® Excel.

Figure 5.1. High-Level Data Sort



CODAP > Records

Status | Country: United States of America | Plant | Record Year: 2017 | Clear

18 records found, displaying all records.1

EID	Status	Plant	Date	Created	by	Updated
4911	Approved	V.C. Summer	2017/01/11	2017/01/26	lydell_b	2017/01/26
4912	Approved	FitzPatrick	2017/01/14	2017/01/26	lydell_b	2017/09/05
4918	Approved	Seabrook	2017/01/21	2017/02/15	lydell_b	2017/02/15
4913	Approved	FitzPatrick	2017/01/22	2017/01/26	lydell_b	2017/09/05
4921	Approved	McGuire-2	2017/02/23	2017/03/10	lydell_b	2017/05/09
4947	Approved	McGuire-2	2017/02/23	2017/05/09	lydell_b	2017/05/09
4931	Approved	Millstone-2	2017/02/28	2017/04/10	lydell_b	2017/04/10
4944	Approved	Byron-1	2017/03/03	2017/05/08	lydell_b	2017/05/08
4946	Approved	Byron-1	2017/03/05	2017/05/08	lydell_b	2017/05/08
4945	Approved	Byron-1	2017/03/06	2017/05/08	lydell_b	2017/05/08
4961	Ready NC	South Texas-1	2017/03/17	2017/08/16	lydell_b	2017/09/01
4932	Approved	Turkey Point-4	2017/03/17	2017/04/11	lydell_b	2017/04/11
4939	Approved	Brunswick-2	2017/04/06	2017/04/26	lydell_b	2017/04/26
4965	Approved	Diablo Canyon-1	2017/04/28	2017/08/28	lydell_b	2017/08/28
4948	Approved	Limerick-2	2017/05/08	2017/05/23	lydell_b	2017/07/14
4958	Approved	Vogtle-2	2017/06/28	2017/07/24	lydell_b	2017/09/01
4971	Approved	Indian Point-3	2017/06/30	2017/09/20	lydell_b	2017/09/20
4963	Approved	Perry-1	2017/08/18	2017/08/24	lydell_b	2017/08/24

Figure 5.2. SEARCH for PWSCC Data Records by Event Date, Event Type & System

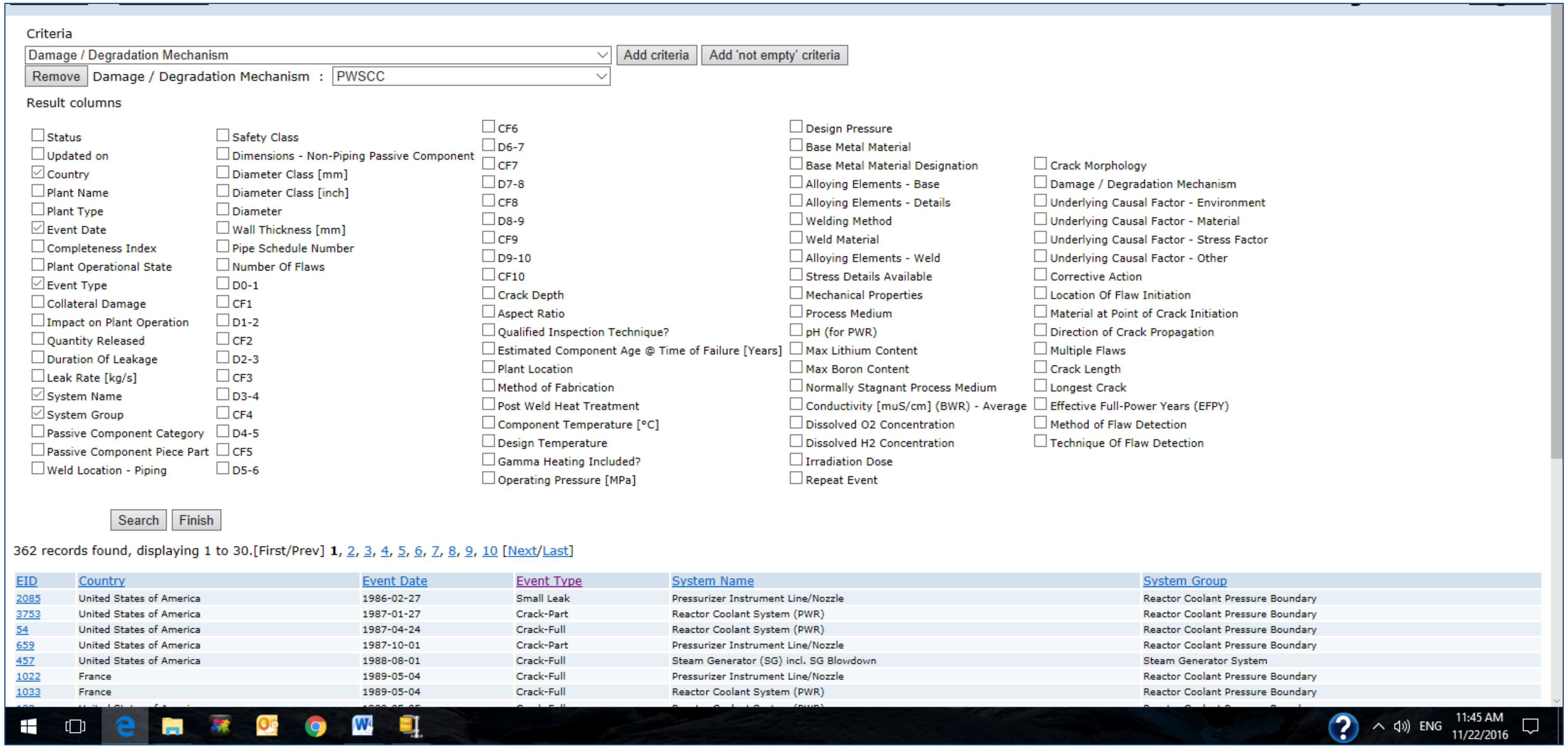


Figure 5.3. Query Example Using "STATISTICS" (Partial Screenshot)

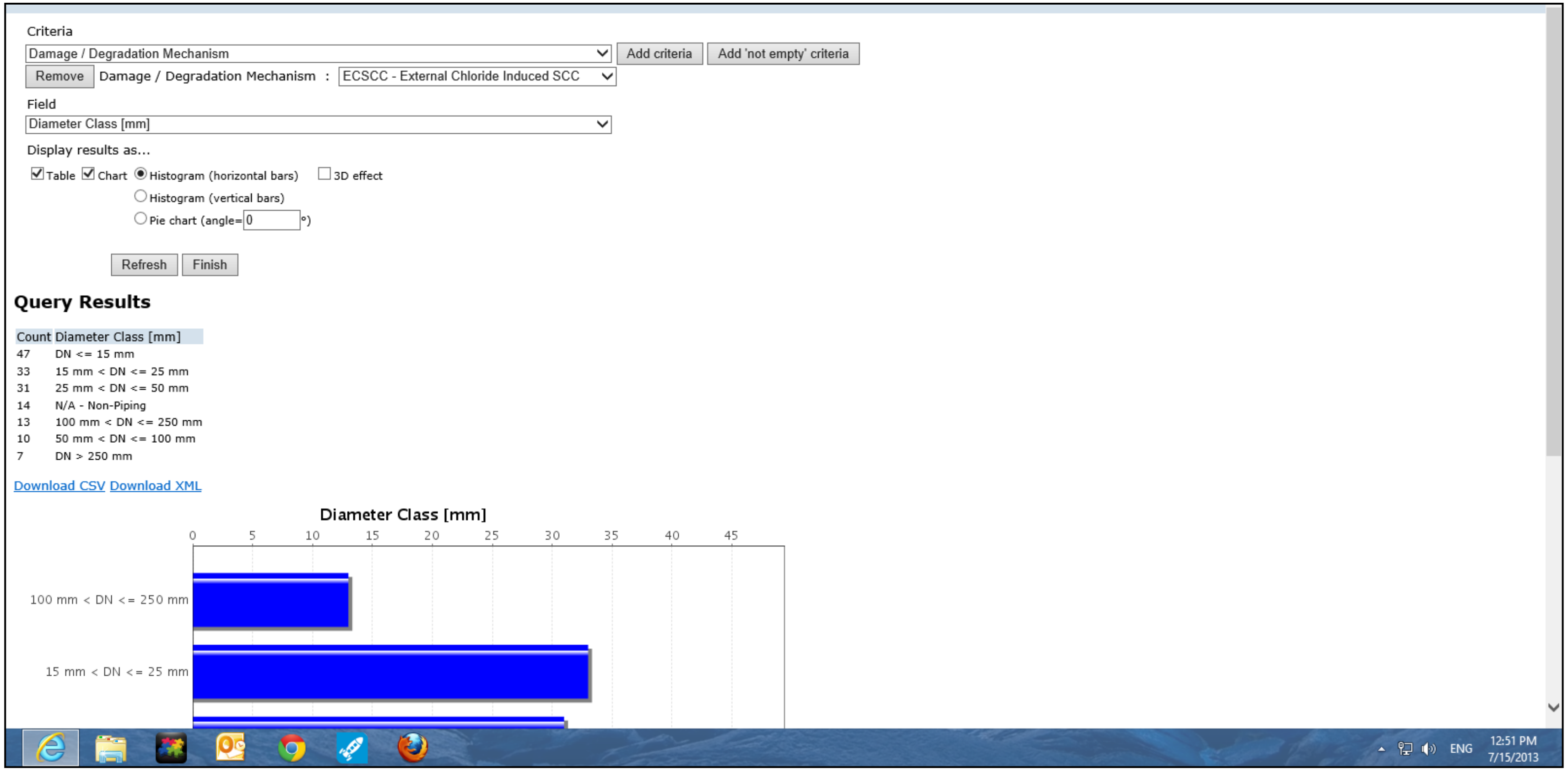
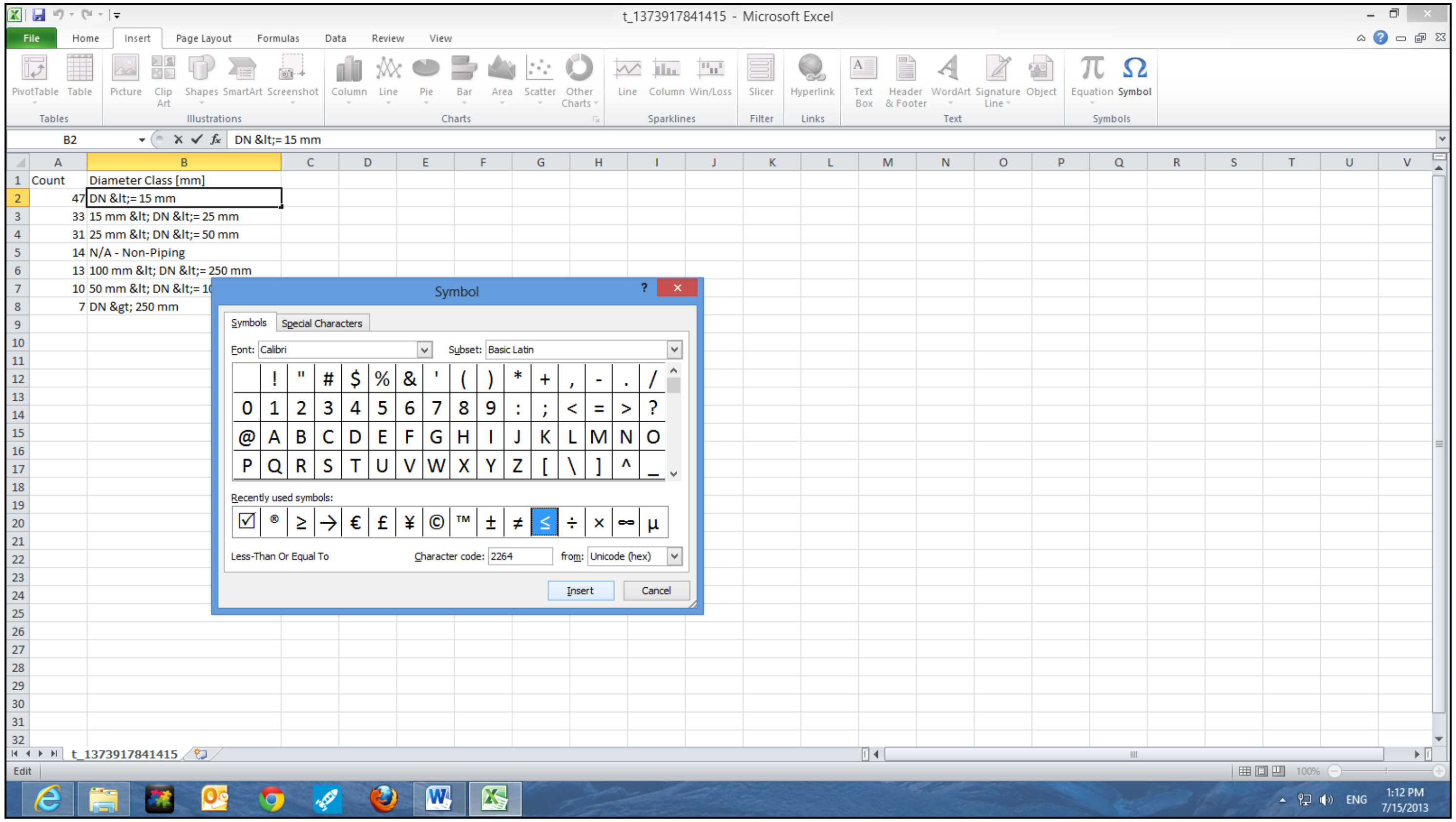


Figure 5.4. CSV-File Example



5.4. Export function

The online version of the CODAP event database is a central repository of event records and supporting documents (e.g. root cause analysis reports, isometric drawings). The database includes provisions for conducting simple queries. In its current form, advanced database applications should be performed on a local computer or computer network, however. The "export function" of the online version facilitates the transfer of selected data records or the entire database to a local computer or computer network.

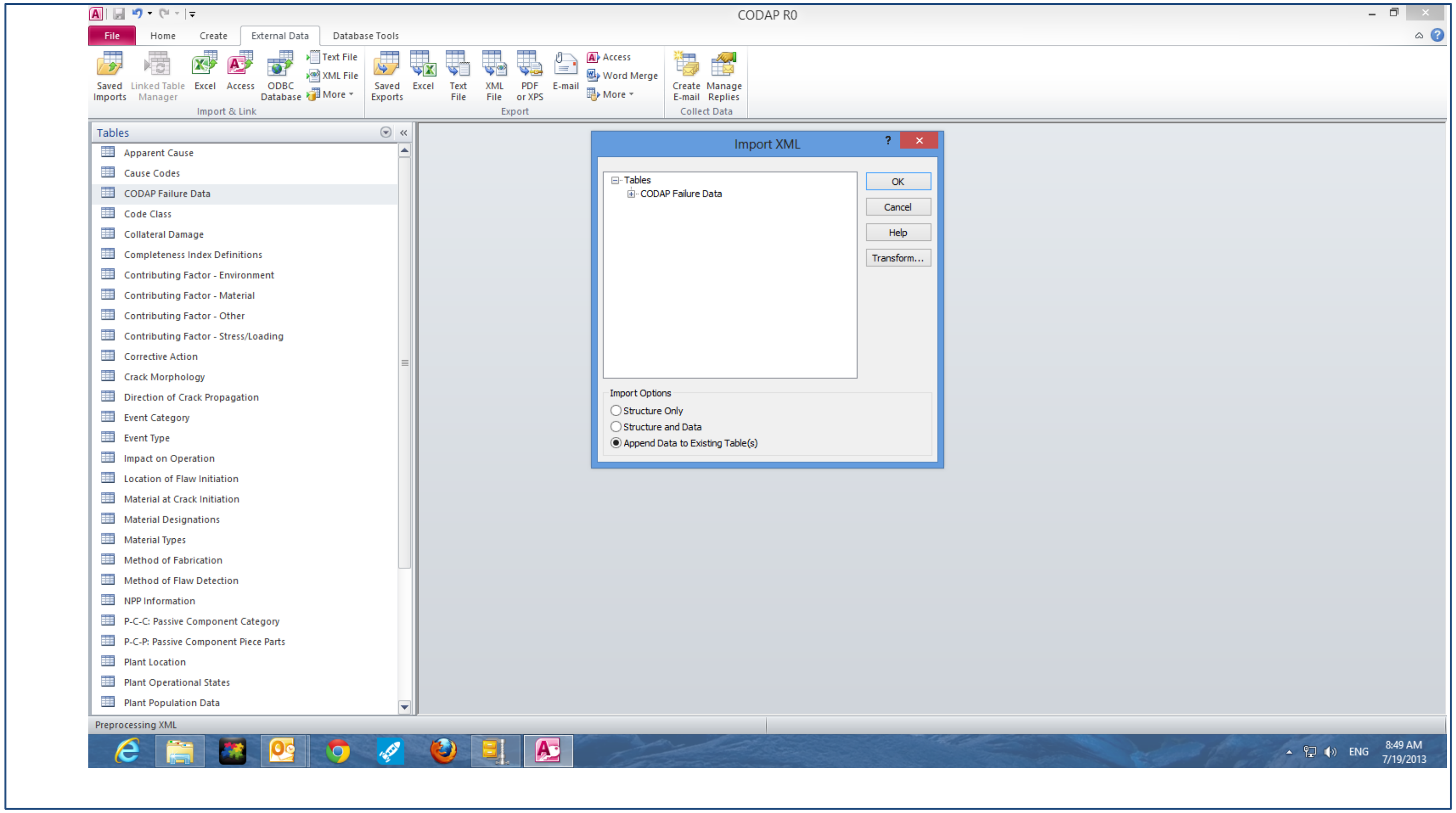
Downloading records from the online version is straightforward. Pressing the "Export" button returns a listing of all records. Selected records or the entire database can be exported to a local computer. The online version creates a zip-file ("Export" file) that can be opened or saved to a local disc. The data records are converted to a XML file format (Extensible mark-up language) that is compatible with Microsoft® Office programs (e.g. Access, Excel, Word). Note that the full CODAP event database is a major collection of information organised in a structured manner. It is a relational database and all data relationships must be retained (or enhanced) in order to support advanced applications. The Microsoft® Access software platform is recommended for the transfer of data from the online version to a local computer or computer network. An Access template is available from the CODAP work area[22.] Other equivalent database software platforms may also be considered.

The Microsoft® Office products are pre-programmed for XML file formats. XML files can be uploaded and formatted using an existing template (e.g. database platform). For illustrative purposes, this section uses an Access database template to facilitate the transfer of data from the online version to a local computer environment. A successful transfer of data involves the following steps:

1. In the online version, go to "export".
2. At the bottom of the screen three options are listed; "select all", "clear selection", and "continue with selected records." Invoking "continue with selected records" returns a new screen with "export records" at the bottom of the screen.
3. Invoking "export records" returns a "file download" window. At this point, define the path for the data transfer (from oecd-nea.org to local disc and folder).
4. Open access database template and go to the "external data" folder and then to "Import XML file."
5. Specify the data source, and once defined press "ok" and check "append data to existing table(s); Figure 5.5.
6. When using the template (which is available from the CODAP work area), this completes the data download process. The XML-file is automatically imported into the "CODAP failure data" table.
7. In case the template is not used, data format validation must be performed to ensure full database functionality. Note that in converting the XML file all database fields are assigned data type "text." Therefore, a data validation must be performed consistent with database field definitions as documented in the coding guideline.

22. The template preserves all built-in data relationships. If template is not used, then the analyst must manually restore data relationships as needed.

Figure 5.5. Importing a XML-File to Microsoft® Access Template



6. Future developments

At its eleventh working group meeting (23-24 February 2016), the CODAP project review group (PRG) approved a database improvement plan to be implemented in two phases over an 18-month period. Phase one involves certain subtle modifications to the existing software to improve the user friendliness. Phase two involves a significant programming effort to produce an advanced, state-of-the-art database user interface. A software requirements specification (SRS) has been developed to establish the basis for an agreement between the database users (i.e. the CODAP PRG) and the developer (NEA-IT) on what the software product is expected to do.

6.1. CODAP improvement plan phase one

The purpose of phase one is to implement certain subtle software changes to the existing CODAP event database. First, the database structure will be simplified[23]. Second, data input will be via three input forms[24] instead of the current single input form. When fully implemented, the ultimate objective of the proposed changes is to make the practical database usage more intuitive.

In its current form, database queries are performed via the statistics page. As currently implemented, the current "statistics" functions are sub-optimal and do not support the definition of multi-attribute cross-tab queries. In option one, the statistics page will include a set of standardised queries that are invoked by pressing a corresponding "query button":

- primary water SCC operating experience (OE) summary
- intergranular SCC OE summary
- fatigue OE summary (Low-cycle fatigue, high-cycle fatigue and thermal fatigue)
- buried pipe OE summary
- socket weld OE summary
- WWER OE summary
- flow-accelerated corrosion (FAC) OE summary
- cast austenitic stainless steel (CASS) OE summary

23. The current database structure consists of 102 fields plus lookup tables. The new database structure will have ca. 60 field plus lookup tables and without any loss of information.

24. The three forms are titled "Event information", "Flaw size & NDE information", and "Root cause evaluation".

6.2. CODAP improvement plan phase two

The project review group (PRG) has worked extensively towards making the CODAP event database both user-friendly and applications-oriented. Full achievement of a frequently used and fully recognised (in an organisational sense) international event database has not yet been reached, however. Over the years, the PRG has identified numerous impediments regarding an active and timely data exchange. These impediments centre around three aspects of CODAP: 1) overly complex database structure, 2) tedious data entry process, and 3) non-optimum search and query functions. Each of the three "impediments" shall be addressed in phase two of the improvement plan.

In the context of nuclear plant ageing management, structural integrity assessments and probabilistic safety assessment (PSA), an objective of an event database such as CODAP is to provide complete and comprehensive information on the operating experience so that independent and realistic "measurements" of material performance can be obtained. Therefore, phase two has two "target success criteria." First, the new software should motivate project member organisations to actively participate in data exchange. Second, the new software should encourage PRG members to actively utilise the database. The CSNI project review group in 2014 recommended that the CODAP project put in place operating procedures and processes whereby future national data submissions are commensurate with the number of operating reactors. By addressing the three impediments described above, the database modifications in phase two are intended to greatly facilitate data entry and ultimately lead to a greater percentage of events being recorded within the database by each country. A summary of the events recorded in the database for each country is provided in Table 6.1.

Table 6.1. OPDE/CODAP Data Submission Summary

Member Country	Validation Status as of September 2017				Total No. Records [% of Total]	Comment
	Approved	Ready for QA	Ready for Review by NC	Draft		
BE - Belgium	8	--	--	--	8 [< 1%]	Participated in OPDE 1st term only
CA - Canada	211	6	1	2	220 [4.5%]	
CH - Switzerland	91	--	7	1	98 [2%]	
CZ – Czech Republic	31	--	--	--	31 [< 1%]	
DE - Germany	354	--	1	2	357 [7.3%]	
ES - Spain	54	--	--	1	55 [1%]	
FI - Finland	55	--	2	--	57 [1.1%]	2002-2014 PRG Member
FR - France	140	--	27	--	167 [3.4%]	
JP - Japan	288	--	--	--	288 [5.9%]	
KR – Korea	78	--	5	--	83 [1.7%]	
SE - Sweden	365		1	--	366 [7.5%]\	2002-2014 PRG Member
SK – Slovak Republic	2		10	--	12 [< 1%]	Joined project in 2011
TW – Chinese Taipei	21	--	4	--	25 [< 1%]	Joined project in 2011
US – United States of America	3146	--	3	--	3149 [64%]	

Member Country	Validation Status as of September 2017				Total No. Records [% of Total]	Comment
	Approved	Ready for QA	Ready for Review by NC	Draft		
ALL	4848	6	61	6	4921	

The completeness and comprehensiveness of the database are key factors in motivating materials and nuclear safety specialists to use the database. That is, the ability of the database to capture all key events within respective PRG country.

6.2.1. Phase two success criteria

A main objective of CODAP phase two is to re-design the web based work space in order to address the three "impediments" as defined above. The original database structure was defined by the PRG to ensure that all known material degradation mechanism conjoint requirements were being addressed. This database structure did not sufficiently differentiate between passive component reliability attributes and influence factors, however. Event reports that provide the fundamental input to CODAP typically address all relevant reliability attributes (e.g. dimensional data, material type and material designation). Information on influence factors (e.g. water chemistry, mechanical properties, material chemical composition, and irradiation dose) typically must be derived from information sources other than event reports. Hence, data input involves a substantial amount of additional processing in order to fill in all data fields.

On the basis of past experiences in working with the existing CODAP event database the PRG must precisely define how to address the three impediments; that is, 1) overly complex database structure, 2) tedious data entry process, and 3) non-optimum search and query functions. This is a critical task in the CODAP phase two work plan.

6.2.2. Option two conceptual user interface

Conceptual CODAP phase two web pages are shown in Figures 6.1 and 6.2. Figure 6.1 is intended to represent the CODAP event database portal (or "Main Menu"). It is divided into five areas. General project information and recent updates of general interest are to be displayed in the main area. The "public area" has links to project reports (e.g. status summaries and topical reports). Access to the "project information tools" is restricted to CODAP PRG members and other authorised users such as TSOs. In the "database user area" authorised users have limited access to the event database; searches and queries may be performed and results saved & downloaded. Finally, in entering the "PRG member area" complete access to the database is obtained.

The conceptual web page for the "PRG member area" is displayed in Figure 6.2. The intent of the "YYYY data submission status" is to provide automatically updated, current information on data submission status and data validation status. The work area consists of three fields:

- New data submission. This area provides links to the data input area. The user will have the option of performing a pre-screening of database fields to be invoked by the software. For example checking the "piping checkbox" implies that the program will request piping dimensional data. When checking the "reactor internals checkbox" those database fields specific to piping components will not be invoked.

- Updates/edits. In this area the user can search for records that are not yet approved. As is the case with the current database, the software responds by listing records for which additional information is needed and with links to the data input form.
- The "download area" shall be equivalent to the current version of the database. Additional options for database conversions may be considered; i.e. database conversion formats in addition to that based on the current Access template format.

6.3. Advanced database applications

The future development includes the consideration of "advanced database applications." This implies using a novel approach to data analysis of location-specific, material-specific, and degradation mechanism (DM) specific structural reliability parameters. A methodology for obtaining structural reliability parameters such as rate of degradation conditional on material, pipe size and operating environment and conditional pipe failure probability given a certain degraded state builds on established statistical models and includes full recognition of the different sources of uncertainty. Additionally and in the context of probabilistic safety assessment (PSA), a practical application needs to be fully risk-informed, which implies that optimum use is made of the best available information about structural integrity analysis, relevant operating experience data, in-service inspection practices, and degradation mitigation practices.

"Data specialisation" is an important aspect part of PSA applications. Data specialisation involves updating generic, industry-wide data parameters with plant-specific data. Typically, the data updating is accomplished using a Bayesian framework in which well qualified generic data is represented by a prior distribution. In piping reliability analysis, data specialisation includes the following tasks:

Figure 6.1. Conceptual Web Page / CODAP "Portal" (or "Main Menu")

AEN NEA **CODAP** OECD

Component Operational Experience, Degradation and Ageing Programme Project Database

Project History

- Background
- Project Objectives
- Project Reports
- Technical Reports
- PPT Presentations
- Conference Papers

CODAP Information Tools

- Applications Handbook
- Coding Guideline
- Knowledge Base

PRG Member Area

- Create – New Data Entry
- Search
- Query
- Apply
- Database Tools

Database Users

- Search
- Query
- Create Reports

Welcome to CODAP*. CODAP is one of four OECD Nuclear Energy Agency database projects (CADAK, CODAP, FIRE & ICDE); for additional information, go to http://www.oecd-nea.org/jointproj/). Established in 2002 as a multi-lateral cooperative project to collect and evaluate operating experience data on degradation and failure of metallic piping components and selected metallic non-piping passive components, CODAP has produced an extensive web based event database. Eleven countries have signed the current (2015-2017) "Terms and Conditions." The CODAP event database is restricted to PRG Members.*

How to Become a Member*. Project membership is open to any nuclear industry organization with the proviso that it can supply operating experience data in accordance with the CODAP Terms and Conditions. For additional information, please contact the Project Secretary olli.nevander@oecd.org*

Project News

Upcoming Meetings

Public	*Restricted – PRG & Database Users*	*PRG Members Only*	*Database Users Only (e.g. TSOs, PRG Contractors)*

Figure 6.2. Conceptual web page/PRG member area

CODAP

Component Operational Experience, Degradation and Ageing Programme Project Database

PRG MEMBER AREA
DATABASE MAINTENANCE

New Data Submission (new window)
Basic Information
☑ Check if Piping
☑ Check if Rx Internals
☑ Check if "Other"
Optional Information

2015 Data Submission Status

The National Coordinators are responsible for data submissions. The preferred method for submitting new data to the database is via the web-based interface. Data submissions may also be handled by e-mail with event information attached in Microsoft Access, Excel or Word file format. The Operating Agent will ensure that data submissions via e-mail be uploaded to the Online Version of the event database. Respective NC remains responsible for data validation.

Country	Status of Data Validation			
	Approved	Ready for QA	Ready for Review by NC	Draft
CA	205			6
CH	91		4	1
CZ	25			
DE	351			1
ES	48		2	
FI	55		2	
FR	131		22	
JP	288			
KR	70		1	
SE	365		1	
SK	2		5	
TW	12		2	
US	3041		23	5
Totals:	4684		62	13

CODAP DATA SUBMISSIONS

PRG Member	CY 2011	CY 2012	CY 2013	CY 2014	CY 2015	CY 2016	CY 2017	Total as of Today's Date
Canada	No data submittals - the work scope focused on finalizing DB structure, developing & implementing the Web-Based Event Database	1	25	8	18			51
Chinese Taipei		--	6	9	--			15
Czech Republic		--	1	3	--			4
Finland		--	--	9	1	N/A	N/A	10
France		--	--	17	5			22
Germany		8	4	10	2			24
Japan		--	--	1	--			1
Korea (Republic of)		--	17	1	2			20
Slovak Republic		1	--	4	--			5
Spain		--	3	2	--			5
Sweden		--	--	--	1	N/A	N/A	0
Switzerland		1	5	1	1			8
USA		33	61	56	30			180
Totals:		44	122	121	60			347

Notes

CODAP TOR	"Each Participating Country shall submit data and general information on component degradation and failure events in English through its National Coordinator referred to in Paragraph 16 (of the TOR) above"
CODAP-OP	"The data exchange is carried out through signatories in the participating countries, with the possibility of delegating to other organizations."
KR - CODAP08	36 legacy records to be input to database
SK - CODAP07	Screening of Bohunice-3/4 Events→ 29 events selected for CODAP. Also note, the CY2014 records include event data & plant name but no other information
JP - CODAP03	Presentation of "Recent Experiences Related to Pipe Wall Thinning in Japan" - 59 event summaries included in presentation material.

Updates/Edits	Search for Pending Actions Country Status	Link to Pending Actions (this window provides list with link)
Download Area Status Country Plant Event Year Select	New Events of Potential Interest	

- Update of existing piping reliability parameter estimates by using new service experience data ("routine" or ordinary data specialisation).
- Modifying generic piping reliability parameter estimates to account for impact on reliability by changes to an inspection programme, or DM mitigation such as full structural weld overlay (FSWOL), mechanical stress improvement process (MSIP®), and use of DM-resistant material.
- Derivation of DM-centred pipe failure rates and rupture frequencies. Included in this task is development of conditional rupture probability (CRP) models that are conditional on the presence of a specific active or assumed inactive degradation mechanism.
- Derivation of piping reliability parameters for new reactor designs on the basis of existing industry-wide service experience data. This involves informed application of lessons learned from the GenI, GenII and GenIII reactor operating experience.
- For some PSA applications pipe rupture frequencies have been developed for different through-wall flow rate categories. For example, "spray events" (≤ 5 kg/s), "general flooding" (between 5 kg/s and 100 kg/s) and "major flooding" (> 100 kg/s). To remove conservatism a refined treatment of flow rate ranges to parse the pipe rupture frequency for flow rate ranges of varying sizes may be warranted.
- The quality of a data specialisation task is a function of the analyst's knowledge and experience and how a parameter estimation task is structured to adequately address a specific application requirement. Guidelines and best practices for piping reliability are developed that address:
    - Knowledge Base. A fundamental basis for a qualified piping reliability analysis rests on a deep understanding of how, the typically robust metallic piping systems degrade and fail or sustain damage due to different off-normal operating environments. Also of importance is a deep understanding of piping system design principles, including the different piping construction/fabrication practices.
    - Service Experience Data. Under what conditions can service experience data support quantitative piping reliability analysis? The completeness and comprehensiveness of a database are essential characteristics for a database to support the derivation of "robust" reliability parameter estimates.
    - Qualitative Analysis Requirements. Query functions are defined to extract event population and exposure term data from a comprehensive relational database. Oftentimes, a query definition must address a complex set of reliability attributes and influence factors. The characterisation of aleatory and epistemic uncertainties depends on the intrinsic qualities of a query definition.
    - Quantitative Analysis Requirements. Pipe failure rate calculation is based on event populations that reflect different piping designs. Therefore, an established practice is to apply a Monte Carlo posterior weighting technique to synthesise the variability in weld counts and DM susceptibility. Pipe rupture frequencies are calculated for well-defined break sizes and resulting through-wall flow rates. CRP models are required for a pre-defined set of break size ranges.

- Special Considerations. Certain follow-up (or sensitivity) studies may have to be performed once a base case set of reliability parameters have been obtained.

Five types of metrics are considered in quantitative piping reliability analysis in support of PSA: 1) failure rate, 2) conditional failure probability, 3) inspection effectiveness, 4) DM mitigation effectiveness, and 5) ageing factors. A pipe failure event database cannot support failure rate estimation, unless the database also includes extensive piping system design information that yield information on the total piping component population that has produced the failure observations; i.e. exposure term data. Relative measures of piping reliability such as conditional failure probabilities can be generated by querying an event database. The statistical robustness of such relative measures is correlated with the completeness of the event population.

Completeness and comprehensiveness of a service experience database should be ensured through a sustained and systematic maintenance and update process. Completeness is an indication of whether or not all the data necessary to meet current and future analysis demands are available in the database. The comprehensiveness of a service experience database is concerned with how well its structure and content correctly capture piping reliability attributes and influence factors. A clear basis should be included for the identification of events as failures.

The inherent latency in structured data collection efforts is on the order of five years. This means that ca. five years could elapse before achievement of high confidence in data completeness. In other words, around 2020 the data mining for the previous ten years (2005-2015) would be expected to approach "saturation" (as in high confidence in completeness of a database). Could "cliff-edge-effects" (e.g. small change in input parameter resulting in large results variation) affect an analysis due to database infrastructure factors? It depends on the maturity of inspection programmes and our state-of-knowledge concerning certain degradation mechanisms. Considerations about the use of up-to-date failure data is intrinsically assumed to be factored into an analysis task.

The design and infrastructure associated with a service experience database should be commensurate with application demands and evolving application requirements. In PSA, the completeness of a relevant event population should be validated, either independently or assured through a sustained maintenance effort. To achieve the objectives defined for a database, a coding format should be established and documented in a coding guideline. Such a guideline is built on recognised pipe failure data analysis practices and routines that acknowledge the unique aspects of piping reliability in commercial nuclear power plant operating environments. For an event to be considered for inclusion in the database it must undergo an initial screening for eligibility. An objective of this initial screening is to go beyond abstracts of event reports to ensure that only pipe degradation and failures according to a certain work scope definition are included in the database. As stated, the knowledge and experience of the analyst is a key to performing well-qualified piping reliability analysis.

Correlating an event population with the relevant plant and component populations that produced these failure events enables the estimation of reliability parameters for input to a calculation case. The information contained in a database must be processed according to specific guidelines and rules to support reliability parameter estimation. A first step in this data processing involves querying the event database by applying data filters that address the conjoint requirements for pipe degradation and failure. These data filters are integral part of a database structure. Specifically, these data filters relate to unique piping reliability attributes and influence factors with respect to piping system design characteristics, design and construction practice, in-service inspection (ISI) and operating environment. A qualitative analysis of service experience data is concerned with establishing the unique sets of calculation cases that are needed to accomplish the overall analysis objectives and the corresponding event populations and exposure terms.

Most, if not all database applications are concerned with evaluations of event populations as a function of calendar time, operating time or component age at time of failure. The technical scope of the evaluations includes determination of trends and patterns and data homogeneity, and assessment of various statistical parameters of piping reliability. Therefore, an intrinsic aspect of practical database applications is the completeness and quality of an event database. Do the results of an application correctly reflect the effectiveness of in-service inspection, ageing management, and/or water chemistry programmes?

Before commencing with a statistical parameter estimation task it is essential to develop a thorough understanding of the range of influence factors that act on metallic piping components. Database "exploration" (or data reduction) should be an integral part of all qualitative analysis steps to ensure that the defined evaluation boundary is associated with the most relevant event population data and exposure term data. It entails the identification of unique event sub-populations, time trends/temporal changes and dependencies.

The technical approach to estimating pipe failure rates and rupture frequencies is based on the model expressed by Equations (1) and (2) for estimating the frequency of a pipe break of a given magnitude. Typically, the magnitude is expressed by an equivalent break size (EBS) and corresponding through-wall flow rate. The parameter *x* is treated as a discrete variable representing different equivalent break-size ranges.

$$F(IE_x) = \sum_i m_i \rho_{ix} \qquad (1)$$

$$\rho_{ix} = \sum_k \lambda_{ik} P(R_x | F_{ik}) I_{ik} \qquad (2)$$

Where:

$F(IE_x) =$	Frequency of pipe break of size *x*, per reactor operating-year, subject to epistemic (or state-of-knowledge) uncertainty.
$m_i =$	Number of pipe welds (or fittings, segments or inspection locations of type *i*; each type determined by pipe size, weld type, applicable damage or degradation mechanisms, and inspection status (leak test and non-destructive examination). While not explicitly addressed in the given example, for the buried ESW piping the parameter mi corresponds to the total length of piping being analysed.
$\rho_{ix} =$	Frequency of rupture of component type *i* with break size *x*, subject to epistemic uncertainty.
$\lambda_{ik} =$	Failure rate per "location-year" for pipe component type *i* due to failure mechanism k, subject to epistemic uncertainty, equation three below. In this analysis the failure rate is

	calculated on the basis of per linear meter and reactor operating year.
$P(R_x \mid F_{ik}) =$	Conditional rupture probability (CRP) of size *x* given failure of pipe component type *i* due to damage or degradation mechanism *k*, subject to epistemic uncertainty. This parameter may be determined on the basis of probabilistic fracture mechanics, expert elicitation or service experience insights.
$I_{ik} =$	Integrity (RIM) management factor for weld type *i* and failure mechanism *k*, subject to epistemic uncertainty determined by Monte Carlo simulation and Markov modelling. This parameter is not explicitly addressed in this example.

For a point estimate of the failure rate of piping component type *i* and degradation mechanism k:

$$\lambda_{ik} = \frac{n_{ik}}{\tau_{ik}} = \frac{n_{ik}}{f_{ik} N_i T_i} \tag{3}$$

Where:

$n_{ik} =$	Number of failures in pipe component of type *i* due to degradation mechanism *k*. The component boundary used in defining exposure terms is a function of the susceptibility to certain damage or degradation mechanisms. A CODAP database query provides this number.
$\tau_{ik} =$	Component exposure population (in component years) for welds of type *i* susceptible to degradation mechanism *k*. CODAP does not include any exposure term data.
$f_{ik} =$	Estimate of the fraction of the component exposure population for piping component type *i* that is susceptible to degradation mechanism k, estimated from results of a formal degradation mechanism evaluation.
$N_i =$	Estimate of the average number of pipe components of type i per reactor in the reactor operating years of exposure for the data query used to determine n_{ik}. Determined from reviews of isometric drawings (fabrication isometrics or ISI isometrics) and ISI programme plans for a representative population of plants and combined with expert knowledge of degradation mechanisms.
$T_i =$	Total exposure in reactor-years for the data collection for component type *i*. CODAP event database provides the number of reactor operating years that produced the operating experience data.

For a Bayes' estimate, a prior distribution for the failure rate is updated using n_{ik} and τ_{ik} with a poisson likelihood function. The formulation of equation two enables the quantification of conditional failure rates, given the known susceptibility to the given damage or degradation mechanism. When the parameter f_{ik} is applied, the units of the failure rate are failures per piping component susceptible to the degradation mechanism of concern.

Applying the above seemingly simple relationships invariably results in significant analysis efforts, however. First, the failure event population(s) must fully match a selected evaluation boundary; i.e. piping system of certain material and in a specific operating environment. The exposure term definition involves extensive reviews of isometric drawing information to correctly address plant-to-plant piping system design variability, which is essential in correctly matching event populations and exposure terms.

For a Bayes' estimate, a prior distribution for the failure rate is updated using n_{ik} and τ_{ik} with a Poisson likelihood function. The formulation of equation three enables the quantification of conditional failure rates, given the known susceptibility to the given damage or degradation mechanism. When the parameter f_{ik} is applied, the units of the failure rate are failures per welds susceptible to the damage or degradation mechanism. This formulation of the failure rate estimate is done because the susceptible damage or degradation mechanisms typically are known from the results of a previously performed degradation mechanism analyses. If the parameter f_{ik} is set to 1.0, the failure rates become unconditional failure rates, i.e. independent of any knowledge about the susceptibility of damage or degradation mechanism, or alternatively that 100% of the components in the population exposure estimate are known to be susceptible to a certain damage or degradation mechanism.

The likelihood of a pipe flaw propagating to a significant structural failure (SF) is expressed by the conditional failure probability $P(R_x \backslash F_{ik})$ where F_{ik} represents degraded condition. When there are limited or no SFs in the database to support a direct statistical estimation of the conditional probability, the assessment can be based on probabilistic fracture mechanics (PFM), expert judgment, and/or service experience data insights. Different PFM algorithms have been developed, but with a focus on fatigue growth and stress corrosion cracking.

There remain issues of dispute with respect to reconciliation of results obtained through statistical estimation versus the physical models of PFM, however. Results from studies to benchmark PFM calculations against field experience have shown PFM computer codes to over-predict pipe failure rates by more than an order magnitude relative to statistical estimates of field experience data. In general, the results obtained with PFM computer codes are quite sensitive to assumptions about weld residual stresses, crack growth rates, and correlations of crack initiation times and growth rates. Also, PFM calculations are invariably done for very specific geometries that may or may not apply to a broader set of evaluation boundaries under consideration in PSA.

7. Summary and recommendations

This report is the fifth CODAP topical report and focuses on the CODAP event database structure and the underlying principles of collecting operating experience data on metallic passive components. The report includes a summary of the CODAP Operating Procedures, the CODAP event database Coding Guideline, and the CODAP Applications Handbook.

7.1. Summary

Since May 2002, the NEA has operated an event database on passive component degradation and failure. During 2002-2011 the project, referred to as OPDE, focused on piping component failures. In May 2011, the project review group approved the transition of OPDE to a new, expanded "NEA Component Operational Experience, Degradation and 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 safety systems, and support systems. It also covers non-safety-related components with significant operational impact. At the present time, 11 NEA member countries participate in the database project. An effort is underway to systematically evaluate the database content and to make a series of database insight reports available to material scientists as well as risk management practitioners. Data exchange among participating organisations promotes understanding of the different national practices regarding reliability and integrity management of passive components.

The CODAP Event Database is a web-based, relational SQL database consisting of approximately 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 probabilistic safety assessment (PSA). The database structure has evolved over a period of fifteen years.

At its eleventh working group meeting (23-24 February 2016), the CODAP project review group (PRG) approved a database improvement plan to be implemented in two phases over an 18-month period. Specifically, the CODAP database improvement plan encompasses two phases. The first involves certain subtle modifications to the existing software to improve the user friendliness. The second involves a significant programming effort to produce an advanced, state-of-the-art database user interface. A software requirements specification (SRS) has been developed to establish the basis for an agreement between the database users (i.e. the CODAP PRG) and the developer (NEA-IT) on what the software product is expected to do. The complete description of the functions to be performed by the software specified in the SRS will assist the potential users to determine if the software specified meets their needs or how the software must be modified to meet their needs.

7.2. Next steps and recommendations

The project review group (PRG) has worked extensively towards making the CODAP event database both user-friendly and applications-oriented. Full realisation of a frequently used and fully recognised (in an organisational sense) international event database has not yet been achieved, however. Over the years, the PRG has identified numerous impediments to an active, comprehensive and timely data exchange. These impediments centre around three aspects of CODAP: 1) overly complex database structure[25], 2) tedious data entry process, and 3) non-optimum search and query functions. CODAP phase two sets out to provide a more user-friendly work space for data entry, data analysis and advanced database applications. Each of the three "impediments" will be addressed in CODAP phase two.

In the context of nuclear plant ageing management, structural integrity assessments and probabilistic safety assessment (PSA), a fundamental objective of an event database such as CODAP is to provide complete and comprehensive information on the field experience so that independent and accurate "measurements" of material performance can be obtained, including the identification of adverse trends. Therefore, phase two of the CODAP database enhancement project has two target success criteria. First, the new software must motivate project member organisations to actively participate in data exchange. Second, the new software must encourage PRG members to actively utilise the database. The CSNI project review group in 2014 recommended that the CODAP project puts in place operating procedures and processes whereby future national data submissions are commensurate with the number of operating reactors. CODAP phase two is intended to be one step towards achieving of a more "balanced" event database.

With respect to the continued database development and maintenance (i.e. data submissions and validation) it is recommended that the following items be considered in the ongoing active data submission activities by the CODAP PRG Members as well as in the current programme for an enhanced version of the online database ("CODAP option two" Project)[26]:

- Implement a coding navigation tool that, for example, links the drop-down menu for "passive component category" with the drop-down menu for "passive component type".
- Encourage the PRG Membership to more actively share metallic passive component operating experience insights. As a standing item, future working

25. The current database structure was approved by the project review group during the first year of the first term (2011-2014) of the CODAP project.

26. Approved by the CODAP PRG at its eleventh working group meeting (May 2015), "CODAP option two" entails the development of software requirements specifications for an enhanced web-based database.

group meetings should focus on technical discussions on how to utilise CODAP and how to share data analysis insights with the nuclear safety community.
- Expand the sharing of operating experience data within the PRG. Future working group meetings should include as a standing item on national overviews of recent operational events, including the findings of root cause analyses.

The CODAP PRG faces two important future challenges. Firstly, while efforts have been made to promote CODAP and associated data project products to the nuclear safety community at large, there remain programmatic issues relative to how to make the restricted CODAP event database available to PSA practitioners. Secondly, work remains to be done to develop PSA-centric database application guidelines and the associated analytical infrastructure (i.e. piping reliability analysis techniques and tools). Two initiatives are under consideration by the PRG to address the stated challenges. The working group on risk assessment (WGRISK) of the Committee on the Safety of Nuclear Installations (CSNI) is planning the "joint workshop on use of NEA data project operating experience data for probabilistic risk assessment." The CODAP PRG intends to actively support this joint workshop. Additionally, a proposal has been made for an international benchmark exercise concerning the use of operating experience data to quantify piping reliability parameters for input to a standard problem application, e.g. risk-informed operability determination.[27]

27. The topic of an international benchmark exercise has been under discussion since the inception of the OPDE/CODAP project.

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9. Appendix
CODAP database structure

Table 9.1. CODAP Database Field Definitions & Coding Guidelines

Item No.	Field Name	Type	Description	User Instruction/Note
FORM #1 – EVENT NARRATIVE – MANDATORY				
001a	REPRESENTATIVE EVENT (RE)	Yes/No	Identifies a record considered representative of other similar events	Indicates that detailed information is available. All relevant information are to be provided for the RE only.
001b	REFERENCE CASE ID	Text	Unique ID to indicate that a record is related to a "Representative Event"	CC-## where CC is country code and ## is number
001c	MER	Yes/No[29]	**M**ultiple **E**vents **R**eport	Some events result in augmented inspection of other, similar locations. The "MER" box is checked if additional flaws are found **and** if these additional flaws can be uniquely defined. Add new database records for each additional, uniquely defined degraded component. CODAP-CG includes additional details.
002	COMPLETENESS INDEX	Number	Roll-down menu with options & definitions.	This field supports database management activities and applications. This index is assigned by Operating Agent.
003	EVENT DATE	Date	Event date or date of discovery	Online version uses the format YYYY-MM-DD
004	PLANT NAME	Text	Roll-down menu with list of all commercial nuclear power plants	Organised by country, the Online Version includes a NPP information library that includes plant type, design type, NSSS vendor and name of constructor.[30]

29. "Yes" = True; "No" = False. Depending on the context, a check box without check mark implies either "No", "Not Available", "Not Applicable", or "Unknown/Pending."

30. This is a "database-within-the-database" and builds on information from the IAEA power reactor information system (PRIS).

Item No.	Field Name	Type	Description	User Instruction/Note
005	PLANT OPERATIONAL STATE	Text	Plant operational state (at the time of discovery) per generally accepted or standard nomenclature. Roll-down menu[31] with the following options: • CSD – Cold Shutdown (other than Refuelling Outage) • HSD – Hot Shutdown • HSB – Hot Standby • Power Operation • Low Power Operation • Refuelling • Shutting Down • Starting Up	This field is used as a data filter when defining a database query. For example, it allows the user to quickly differentiate between events with an operational impact (e.g. forced shutdown) and those events discovered through scheduled or augmented inspections.
006a	REFERENCE - PRIMARY	Text	Primary reference	Upload original reference as a PDF or TIF. Except for title, no translation into English is required. The original language should be included as well as if the material is confidential or not. CODAP operating procedures address handling of confidential information. Also, refer to item n° 16; PDF1/PDF2/PDF3/PDF4 could include isometric drawings, photographs, etc.
006b	PRIMARY REFERENCE IN PUBLIC DOMAIN?	Yes/No	Check box to indicate if primary reference is restricted (confidential) or not – mark box if YES	
006c	PDF1	Hyperlink	Provision for uploading original primary reference as PDF	
007a	REFERENCE - SECONDARY	Text	Secondary (or supplemental) reference	
007b	SECONDARY REFERENCE IN PUBLIC DOMAIN?	Yes/No	Check box to indicate if secondary reference is restricted (confidential) or not – mark box if YES	

31. Contact the Operating Agent for any change requests concerning the roll-down menus.

Item No.	Field Name	Type	Description	User Instruction/Note
007c	PDF2	Hyperlink	Provision for uploading original secondary reference as PDF	
008a	REFERENCE - TERTIARY	Text	Tertiary (or supplemental) reference	
008b	TERTIARY REFERENCE IN PUBLIC DOMAIN?	Yes/No	Check box to indicate if tertiary reference is restricted (confidential) or not – mark box if YES	
008c	PDF3	Hyperlink	Provision for uploading original tertiary reference as PDF	
009a	REFERENCE - QUARTIARY	Text	Quartiary (or supplemental) reference	
009b	QUARTIARY REFERENCE IN PUBLIC DOMAIN?	Yes/No	Check box to indicate if quartiary reference is restricted (confidential) or not – mark box if YES	
009c	PDF4	Hyperlink	Provision for uploading original quartiary reference as PDF	

Item No.	Field Name	Type	Description	User Instruction/Note
010	EVENT TYPE	Text	• Roll-down menu with the following options: • Wall Thinning • Crack-Full (through-wall crack w/o active leakage) • Crack-Part (part through-wall crack) • Leak (leak rate within Tech. Spec. limit) • Large Leak (leak/flow rate above Tech. Spec. limit) • P/H-leak (pinhole leak) • Recordable indication • Reportable Indication • Rupture (large flow rate, loss of structural integrity) • Severance • Small Leak (leak rate well below Tech. Spec. limit)	This field is used as a database filter for user-defined queries. "Tech. Spec." refers to the technical specifications established for plant operation and includes the limiting conditions for operation. The term "severance" relates to complete structural failure of small-diameter piping
011	Crack Morphology	Text	• Intergranular/Interdendric • Transgranular	This field applies to stress corrosion cracking (SCC) events

Item No.	Field Name	Type	Description	User Instruction/Note
012	EVENT CATEGORY	Text	Roll-down menu with the following options: • CCI-Precursor • Containment Bypass • CCI (Common Cause Initiator) • Internal Flooding • Internal Flooding Precursor • IS-LOCA • IS-LOCA Precursor • LOCA • LOCA Precursor • RCPB Leak • RCP Seal LOCA • RCP Seal LOCA Precursor • System Degraded • System Disabled • Train Degraded • Train Disabled	This field is used as a data filter
013	COLLATERAL DAMAGE	Text	Roll-down menu with the following options: • N/A – None • Adjacent Line Damaged • Flooding of Equipment Area • Jet Stream Impact • Pipe Whip – Adjacent Line Damaged • Spray Impact on Adjacent Equipment • Spurious Fire Protection System Actuation • Loss of Supported Function	This field relates to operational events involving active through-wall leakage on ex-RPV passive component. An active leak in Auxiliary Building/Reactor Building could potentially generate sufficient heat load to activate a Fire Protection Water System resulting in consequential wetting/spraying/flooding of safety-related equipment.

Item No.	Field Name	Type	Description	User Instruction/Note
014	IMPACT ON PLANT OPERATION	Text	Roll-down menu with the following options: • Cooldown (from Hot Shutdown) • Cooldown (from Hot Standby) • Expanded Outage Work Scope • LCO Entry (LCO = Limited Condition for Operation) • Manual Shutdown • Multi-Unit Shutdown • N/A – None • Power Reduction • ESF/RPS Actuation (automatic Rx trip) • System Train Inoperable • Tritium Release to Environment • Turbine Trip / Reactor Trip • Unplanned Outage Work • Shutdown of Normal Letdown (PWR)	Mainly, this field relates to operational events involving active through-wall leakage on ex-RPV passive component. Definition of "LCO" is found in the plant specific Technical Specification document
015	Time-to-Repair TTR-Class	Number	Roll-down menu with the following options: • **1**: TTR ≤ 8 hours • **2**: 8 < TTR ≤ 24 hours; • **3**: 24 < TTR ≤ 96 hours; • **4**: 96 < TTR ≤168 hours • **5**: TTR > 168 hours.	TTR = Time-to-Repair; this field is used as a data filter
016	EVENT NARRATIVE	Memo	Description of plant condition prior to event and plant response during event, method of detection, corrective action plan.	This free format field should include sufficient information to support independent verification of the event classification. ENGLISH LANGUAGE ONLY

Item No.	Field Name	Type	Description	User Instruction/Note
017	LOCATION OF FAILURE	Memo	Location of crack/thinned area/leak/rupture; description of where a degradation or failure occurred. Include sufficient detail to support the consequence evaluation and event classification.	Each component should be uniquely identified using an identifier as indicated on an isometric drawing or in plant reference documentation. This is particularly important in case a single event report relates to multiple degraded or failed passive components. Utilise hyperlinks as needed.
018	PLANT LOCATION	Text	Roll-down menu with the following options: • Auxiliary Building • Cooling Tower (UHS) • Containment (PWR) • Drywell (BWR) • EDG Building • Fuel Transfer Canal • Owner Controlled Area • Radwaste Treatment Building • Reactor Building • Secondary Containment (Annulus) • Steam Tunnel • Torus Area (BWR) • Turbine Building • Wet Well (BWR)	In-plant location of degraded/failed component. Forward change requests to the operating agent
019	QUANTITY RELEASED	Text	Quantity of process medium released [kg]	This may be based on assumptions using information included in the event narrative or based on calculation
020	DURATION OF LEAKAGE / SPILL	Text	Estimated time of leakage/release/spill	Indicate time in minutes
021	LEAK RATE	Number	[kg/s]	Assumed or measured

Item No.	Field Name	Type	Description	User Instruction/Note
022	LEAK RATE ASSUMED OR MEASURED?	Yes/No	Check box	Mark check box if Leak/Flow Rate is measured
023	SYSTEM NAME	Text	System name; this field is supported by a roll-down menu	See **Table B-1** for details; it is not an all-inclusive list and user-defined entries are permitted/encouraged. Forward all change requests to the operating agent.
024	SYSTEM GROUP	Text	Supported by a roll-down menu: • AUXC – Auxiliary Cooling System • CS – Containment Spray System • FWC – Main & Auxiliary Feedwater & Condensate • RAS – Reactor Auxiliary System • RCPB – Reactor Coolant Pressure Boundary • RPV – Reactor Pressure Vessel • SIR – Safety Injection & Recirculation System • SG – Steam Generator System • STEAM – Steam Systems	See **Table B-2** for details. This field is a database filter. Forward all change requests to the operating agent
025	P-C-C (Passive Component Category)	Text	**P**assive **C**omponent **C**ategory – supported by a roll-down menu with current options as indicated in **Table A-3**	This field is a database filter, which supports user-defined database queries. Change requests should be forwarded to the Operating Agent.
026	P-C-T (Passive Component Type)	Text	**P**assive **C**omponent **T**ype Part. Roll down menu with current options as indicated in **Table A-3**.	Change requests should be forwarded to the operating agent.
027	WELD POSITION	Text	Roll down menu	This field is a database filter, and it applies to piping only. Change requests should be forwarded to the operating agent

Item No.	Field Name	Type	Description	User Instruction/Note
028	SAFETY CLASS / CODE CLASS	Number	Roll-down menu with the following options: • 1 • 2 • 3 • 4 (= Non-Code, non-safety related)	This field is a database filter, which supports user-defined database queries. Classification of components differs among participating countries. At the end of the trial period a "classification cross-reference table" will be prepared to show what these differences are.
029	DIMENSIONS	Text	Dimension(s) of non-piping passive component	Dimension of bolting should be given as: "DIAMETER × LENGTH." CODAP-KB includes a Component Catalogue with dimensional data As an example, dimension of bolting should be given as: "DIAMETER × LENGTH.", .
030	DIAMETER CLASS (PIPING)	Number	Roll-down menu with the following options (based on nominal diameter): • 1 – ∅ ≤ 15 mm • 2 – 15 < ∅ ≤ 25 mm • 3 – 25 < ≤ 50 mm • 4 – 50 < ∅ ≤ 100 mm • 5 – 100 ∅ ≤ 250 mm • 6 - ∅ > 250 mm	Database filter for piping components
031	DIAMETER	Number	Measured diameter	
032	Unit	Yes/No	Check Box	Mark check box if unit is [inch]
033	WALL THICKNESS [mm]	Number	Measured wall thickness [mm]	
034	PIPE SCHEDULE	Number	Pipe schedule according to standard commercial pipe sizes (U.S. practice)	For definition, see "Glossary of Terms" (Appendix D)

FORM #2 – ROOT CAUSE INFORMATION – MANDATORY				
035	AGE	Number	In-service component age at time of failure [hours]; respective NC is responsible for ensuring that a given in-service age accounts for repair/replacement history(ies)	Note that the current version of the database platform automatically generates a default component age, which is calculated as: AGE = TEvent_Date – TRx-Crit If the affected component has a repair/replacement history, this should be reflected in the estimated age. If possible (and relevant), the component age should exclude time in other than power operating modes. Note that some systems are required to be operational during non-power operating modes of operation
036	ACTUAL OPERATING TIME OF COMPONENT	Number	If available, this should be in terms of "Effective Full-Power Years" (EFPY)	This should be exclusive of time in other than power operating modes.
037	METHOD OF FLAW DETECTION	Text	Roll-down menu with the following options: • Containment/Drywell Inspection • Control Room Indication/Alarm • ISI – Inservice Inspection • Leak Detection • Routine Maintenance • Maintenance on demand • Periodic Testing • Walkdown Inspection	Forward change requests to the operating agent
038	TECHNIQUE OF FLAW DETECTION	Text	Roll-down menu with the following options: • Eddy Current Testing • Hydrotesting • Inservice Leak Test • Liquid Penetrant Testing • Radiographic Testing	Forward change requests to the operating agent

			• UT-Examination • Video Camera • Visual Inspection/Testing	
039	MATERIAL (Base Metal)	Text	List of check boxes for the following options: • Duplex Steel • High-Performance Stainless Steel • Stainless Steel • Ni-base Alloy • SS/Carbon Steel (stainless steel clad carbon steel) • Carbon Steel • Low Alloy Steel • Other	User-defined entry is permitted. If it is a DM weld, there are two types of base metals. If information is available, include information on the heat treatment method; e.g. MA = mill-annealed, TT = thermal treated
040	MATERIAL DESIGNATION (Base Metal)	Text	Roll-down menu with options as listed in Tables A-4 through A-6	It is not an all-inclusive list and user-defined entries are permitted and encouraged. Forward change requests to the Operating Agent
041	PROCESS MEDIUM at time of detection	Text	Roll-down menu with the following options: • Borated Water • BWR Primary Water – NWC • BWR Primary Water – HWC • BWR Primary Water – HWC+NMCA • Coordinated chemistry • High pH • PWR primary side • Chemical treatment • Condensate • Demineralised Water • Feedwater (Conditioned) • Heavy Water – D2O	Forward change requests to the Operating Agent

			• Radioactive Waste Water • Steam	
042	Damage / Degradation Mechanism	Text	Drop-down menu supported by a roll-down menu	Change requests should be forwarded to operating agent
043	CONTRIBUTING FACTOR -1 (ENVIRONMENT)	Text	Roll-down menu with the following options: • Boric Acid/Stagnant Flow Conditions • Contamination – ID (e.g., chlorides, sulfides) • Contamination – OD (e.g., chlorides, sulfides) • Cyclic loading • Demineralizer Breakdown – pH Decrease • HF: Construction/Installation Error • HF: Repair/Maintenance Error • HF: Welding Error • High Residual Stresses • Hydrogen Concentration • Increased Concentration of Inclusions • ISI Programmatic Deficiency • Oxygen Containing Water • Stress Riser due to Root Notch • Thermal Fatigue • Transient Stress During Start-up • Use of Higher-Strength Material	HF = Human Factor (includes safety culture issues). Forward change requests to the operating agent
044	CONTRIBUTING FACTOR – 2 (MATERIAL)	Text	Roll-down menu to be developed	Forward change requests to the operating agent

045	CONTRIBUTING FACTOR – 3 (STRESS FACTOR)	Text	Roll-down menu to be developed	Indicate whether there is evidence of repair(s) performed on component prior to discovery of flaw (e.g. repair performed during plant construction)
046	CONTRIBUTING FACTOR – 4 (OTHER)	Text	Roll-down menu to be developed	Forward change requests to the operating agent
047	ROOT CAUSE ANALYSIS	Memo	Narrative of root cause analysis results	The text should include information on the type of examinations performed and the results.
048	CORRECTIVE ACTION	Text	Roll-down menu with the following options: • Abandon – Cap • Base Metal Repair • Code Repair • Electro-Discharge Machining • Evaluation – Accepted for Continued Operation • Half-nozzle Technique • IHSI Process (Induction Heat Stress Improvement) • Isolate – Cap • Isolate – Temporary • L-SIP – Laser Stress Improvement Process • Left As-Is • Mechanical Clamp • MNSA – Mechanical Nozzle Seal Assembly Installed • MSIP – Mechanical Stress Improvement Process • Repair • Repair – Freeze Seal	The term “temporary repair” implies that a permanent code repair be made at next outage (given it is of sufficient duration) or next scheduled refuelling outage. Forward change requests to the operating agent

			• Replace – In-Kind • Replace – In Kind – Below T-min (FAC) • Replace – New Design • Replace – New Material • Replace – New Material – Below T-min (FAC) • Replace – New Weld Configuration • RPV Head Replacement • Temporary Repair • Temporary Repair – Furmanite Leak Seal Enclosure • Temporary Repair – Welded Plate • Temporary Repair – Mechanical Clamp • Weld Overlay • Weld Overlay – Full Structural • Weld Repair	
049	Weld Repair Description	Memo	Description of weld repair(s) performed prior to component being taken into operation	
050	ADDITIONAL COMMENT	Memo	Any other information of relevance to understanding of underlying causal factors. Also include information on the extent of repair/replacement.	The purpose of this free-format database field is to facilitate future applications, for example, by codifying the information on passive component replacements.
051	FOLLOW-UP INSPECTION	Memo	Free format text field	
052	SPECIFIC REGULATORY ACTION	Memo	Free format text field	

FORM #3 – FLAW CHARACTERISATION – MANDATORY				
053	FLAW DESCRIPTION	Memo	Narrative description of flaw; orientation and size/geometry of crack or fracture	Include any relevant information with respect to actions taken subsequent to discovery
054	LOCATION OF FLAW INITIATION	Text	Roll-down menu with the following options: • Base Metal – Heat Affected Zone • Base Metal – Not Heat Affected Zone • Buttering • Cladding • Weld Metal	Forward change requests to operating agent
055	MATERIAL AT LOCATION OF FLAW INITIATION	Text	Roll-down menu with the following options: • Stainless Steel • Ni-based Alloy • SS/Carbon Steel (stainless steel clad carbon steel) • Carbon Steel • Low Alloy Steel • Other	Forward change requests to operating agent
056	DIRECTION OF FLAW PROPAGATION	Text	Roll-down menu with the following options: • Axial Direction • Circumferential Direction • Oblique Direction • Multiple Directions	Direction as determined by NDE
057	MULTIPLE FLAWS	Yes/No	Multiple flaws in weld-HAZ?	Mark check box if “Yes”
058	nF	Number	Number of flaws	
059	D#-##/CF#	Number	Distance between flaws and length of each flaw. Database fields provided for up to ten flaws	
060	FLAW-DEPTH	Number	Flaw depth – percentage of nominal wall thickness	

061	FLAW-DEPTH	Number	Depth of deepest flaw	Depth of longest flaw (if deepest flaw is not longest)
062	FLAW-LENGTH	Number	Length of deepest flaw	
063	LONGEST CRACK	Number	Length of longest flaw (if deepest flaw is not longest)	
064	ASPECT-RATIO	Number	Ratio of length of deepest crack to depth of deepest crack	The aspect ratio is used in probabilistic fracture mechanics.
FORM #4 – IN-SERVICE INSPECTION (ISI) INFORMATION - OPTIONAL				
065	ISI DEFICIENCY	Yes/No	Mark check box if the pipe failure is attributed to a weakness in ISI program plan, or if the affected component is not included in ISI program.	Example (FitzPatrick, 5/4/1990): "The weld was previously inspected during the 1988 refuelling outage. At that time a "Level III" inspector inspected the weld. Indications were noted with maximum amplitude at 5.5-degrees clockwise, 6.65-degrees counter- clockwise, and 21.5-degrees clockwise. These indications were misinterpreted to be root geometry, since the indications were noted on the opposite side of the weld (beam reflection)."
066	ISI HISTORY / AGING MANAGEMENT PROGRAM	Memo	Include any relevant information about the ISI history (e.g. time of most recent inspection and findings) or maintenance history	The narrative text should differentiate between "scheduled", "augmented", and "mandatory" (by regulatory order/request)
067	QUALIFIED INSPECTION TECHNIQUE	Yes/No	Mark check box if the flaw was detected using a qualified inspection technique	If "Yes", provide relevant background information in database field 049
068	NDE QUALIFICATION BACKGROUND	Memo	Include details on the standard used to qualify the inspection technique	This information should only be included if it is component specific

FORM #5 – SERVICE ENVIRONMENT – OPTIONAL				
069	METHOD OF FABRICATION	Text	Roll-down menu with the following options: • Casting • Forging • Cold Bending • Hot Bending • Seamless Pipe • Seam Welded Pipe	Forward change requests to the operating agent
070	PWHT	Yes/No	If “yes”, provide details in field #71 below	PWHT = Post Weld Heat Treatment
071	PWHT-DETAILS	Memo		
072	COMPONENT TEMPERATURE	Text	Component temperature [º C] (fluid temperature)	
073	GAMMA HEATING INCLUDED?	Yes/No	Mark check box if gamma heating is included in “095” (IRRADIATION DOSE)	This field applies to reactor internals only. “No” implies “does not apply” in the case of ex-RPV components.
074	T-DESIGN	Yes/No	Mark check box if temperature as given in “074” is design value	
075	OPERATING PRESSURE	Text	Operating pressure [MPa]	
076	P-DESIGN	Yes/No	Mark check box if pressure as given in “060” is design value	
077	ALLOYING ELEMENTS (Base Metal)	Text		Of relevance to degradation mechanism
078	ALLOYING ELEMENTS (Details)	Yes/No	Mark check box if detailed information is available	Supply information separately as PDF and attach to record in designated field (utilise Fields 006, 007, 008, 009 as needed).

079	WELDING METHOD	Text	Roll-down menu with the following options: • Shop weld – GMAW • Shop weld – GTAW • Shop weld – SAW • Shop weld – SMAW • Field weld – GMAW • Field weld – GTAW • Field weld – SAW • Field weld – SMAW • Repair weld	Check box for manual vs. automatic welding.
080	WELDING TECHNIQUE	Yes/No	Check box for manual vs. automatic welding.	Mark check box if automatic welding
081	WELD MATERIAL	Text	Roll-down menu.	Forward change requests to operating agent
082	ALLOYING ELEMENTS (Weld Metal)	Text		Supply information separately as PDF and attach to record in designated field of online version
083	STRESS AT LOCATION	Text	Estimated or measured	Differentiate between residual versus operational stresses
084	STRESS DETAILS AVAILABLE	Yes/No	Mark check box if detailed information is available and append as PDF	Supply information separately as PDF and attach to record in designated field of online version
085	MECHANICAL PROPERTIES	Text	For example yield strength, hardness	Indicate if per standard or specification.
086	SURFACE FINISH	Text	Roll-down menu to be developed by PRG	Enter surface finish as text
087	CHEMISTRY HISTORY	Memo	Narrative description of chemistry programme	Include dates of program changes (e.g. start of chemical addition). Include information on method for pH control. Indicate major changes in chemistry, such as transition from NWC to HWC , chemical transients, condenser in-leakage

088	pH	Text		For PWR primary system address whether primary system pH is within or outside limits
089	MAX-LITHIUM CONCENTRATION	Text	Maximum lithium content in [ppb] (PWR)	
090	MAX-BORON CONCENTRATION	Text	Maximum boron content in [ppb] (PWR)	
091	STAGNANT PROCESS MEDIUM	(Yes/No)	A check mark indicates normally stagnant process medium	Should address recent history
092	CONDUCTIVITY - AVERAGE	Number	Conductivity [µS/cm] (BWR) – average	
093	DISSOLVED OXYGEN CONTENT	Number	Dissolved oxygen concentration in [ppm]	
094	DISSOLVED HYDROGEN CONTENT	Number	Dissolved hydrogen concentration [cm3 STP/kg H2O] (PWR)	
095	IRRADIATION DOSE	Text	Maximum neutron fluence [neutrons/cm2]	Method of calculating fluence to be determined
096	REPEAT EVENT	Yes/No	Previous event at this location?	

Table 9.2. Selected Plant System Designators

Designator	Definition
CRD	Control Rod Drive (BWR Hydraulic Scram)
CS	Containment Spray
CVC	Chemical & Volume Control
ECCS	Emergency Core Cooling
Flux Detector	Neutron Flux Detector inside the core (WWER)
HPCS	High Pressure Core Spray (BWR)
HPSI	High Pressure Safety Injection (PWR)
ICS	Isolation Condenser (BWR)
LPCS	Low Pressure Core Spray (BWR)
LPSI	Low Pressure Safety Injection (PWR)
MS	Main Stem
PHTS	Primary Heat Transport System (CANDU)
RCIC	Reactor Core Isolation Cooling (BWR)
RCS	Reactor Coolant System (PWR)
RHR	Residual Heat Removal
RPV	Reactor Pressure Vessel
RR	Reactor Recirculation (BWR)
RVLIS	Reactor Vessel Level Indication System
RWCU	Reactor Water Cleanup (BWR)
SFC	Spent Fuel Pool Cooling
S/G-System	Steam Generator (S/G) incl. S/G Blowdown
SLC	Standby Liquid Control (BWR)
See IEEE Std 805-1984 (IEEE Recommended Practice for System Identification in Nuclear Power Plants and Related Facilities) for information on system boundary definitions and system descriptions.	

Table 9.3. Selected Stainless Steel Designations

National Standard					Chemical Composition [Weight %] - Typical				
EN	**ASTM**	**SS (Sweden)**	**NF (France)**	**DIN**	**C**	**Cr**	**Ni**	**Mo**	**Other**
1.4301	(304)	2333	Z6 CN 18.09	1.4301	0.04	17.0	8.5	--	--
1.4307	304L	(2352)	--	(1.4306)	0.02	18.0	8.0	--	--
1.4541	321	2337	Z6 CNT 18.10	1.4541	0.04	17.0	9.0	--	Ti
1.4306	304L	2352	Z2 CN 18.10	1.4306	0.02	18.0	10.0	--	--
1.4401	316	(2347)	--	(1.4401)	0.04	16.5	10.0	2.0	--
1.4404	316L	(2348)	--	(1.4404)	0.02	16.5	10.0	2.0	--
1.4571	317Ti	2350	(Z6 CNDT 17.12)	1.4571	0.04	16.5	10.0	2.0	Ti
1.4436	316	2343	Z6 CND 17.11	(1.4436)	0.04	16.5	10.5	2.5	--
1.4432	316L	2343	--	(1.4435)	0.02	16.5	10.5	2.5	--
1.4435	316L	2353	Z2 CND 17.13	1.4435	0.02	17.0	12.5	2.5	--
Old SS and DIN-designations within brackets specify a slightly higher Ni-content, which is insignificant for the corrosion resistance. The NF designation within brackets specifies a slightly higher Ni-content than the stated typical value.									

Table 9.4. Expanded Stainless Steel Cross-Reference Table

USA AISI	France AFNOR	Germany		Japan JIS	Russia GOST	Spain UNE	Sweden SIS	UK BSI	European Union EN
		DIN EN 10027-1	DIN EN 10027-2						
201				SUS 201					
301	Z 12 CN 17-07	X 12 CrNi 17 7	1.4310	SUS 301		X 12 CrNi 17-07	23 31	301S21	X 12 CrNi 17 7
301		X3CrNiN17-8	1.4319	SUS 301				301S26	X3CrNiN17-8
302	Z 10 CN 18-09	X9CrNi18-9	1.4325	SUS 302	12KH18N9	X 10 CrNi 18-09	23 31	302S25	X9CrNi18-9
303	Z 10 CNF 18-09	X8CrNiS18-9	1.4305	SUS 303		X 10 CrNiS 18-09	23 46	303S22	X8CrNiS18-9
303 Se	Z 10 CNF 18-09			SUS 303 Se	12KH18N10E	X 10 CrNiS 18-09		303S41	
304	Z 6 CN 18-09	X5CrNi18-10	1.4301	SUS 304	08KH18N10 06KH18N11	X 6 CrNi 19-10	23 32	304S15 304S16	X5CrNi18-10
304 N				SUS 304N1					
304 H				SUS F 304H		X 6 CrNi 19-10			
304 L	Z 2 CN 18-10	X2CrNi19-11	1.4306	SUS 304L	03KH18N11	X 2 CrNi 19-10	23 52	304S11	X2CrNi19-11

USA AISI	France AFNOR	Germany DIN EN 10027-1	Germany DIN EN 10027-2	Japan JIS	Russia GOST	Spain UNE	Sweden SIS	UK BSI	European Union EN
304 L		X2CrNi18-9	1.4307	SUS 304L					X2CrNi18-9
304 LN	Z 2 CN 18-10-Az	X 2 CrNiN 18 10	1.4311	SUS 304LN			23 71	304S6	
305	Z 8 CN 18-12	X4CrNi18-12	1.4303	SUS 305		X 8 CrNi 18-12	23 33	305S19/305S17	X4CrNi18-12
	Z 6 CNU 18-10			SUS XM7					X 6 CrNiCu 18 10 4 Kd
309	Z 17 CNS 20-12	X15CrNiSi20-12	1.4828	SUH 309				309S24	X15CrNiSi20-12
309 S	Z 15 CN 23-13	X7CrNi23-14	1.4833	SUS 309S	20KH23N18			309S24	X7CrNi23-14
310		X15CrNiSi25-20	1.4841	SUH 310	10KH23N18			310S24	X15CrNiSi25-20
310 S		X12CrNi25-20	1.4842	SUS 310S					X12CrNi25-20
310 S	Z 12 CN 26-21	X8CrNi25-21	1.4845	SUS 310S	20KH25N20S2		23 61		X8CrNi25-21
314	Z 12 CNS 25-20	X 15 CrNiSi 25-20	1.4841						X 15 CrNiSi 25 20
316	Z 6 CND 17-11	X 5 CrNiMo 17-12-2	1.4401	SUS 316		X 6 CrNiMo 17-12-03	23 47	316S31 316S17	X 5 CrNiMo 17 12 2

USA AISI	France AFNOR	Germany		Japan JIS	Russia GOST	Spain UNE	Sweden SIS	UK BSI	European Union EN
		DIN EN 10027-1	DIN EN 10027-2						
316	Z 6 CND 17-12	X3CrNiMo17-13-3	1.4436	SUS 316		X 6 CrNiMo 17-12-03	23 43	316S33 316S19	X3CrNiMo17-13-3
316 LN		X2CrNiMoN17-11-2	1.4406	SUS 316LN				316S61	
316 LN	Z 2 CND 17-13-Az	X2CrNiMoN17-13-3	1.4429	SUS 316LN	08KH17N13M2T 10KH17N13M2T		23 75	316S63	
316 F?		X 12 CrNiMoS 18 11	1.4427						
316 N?				SUS 316N					
316 H		X6CrNiMo17-13	1.4919	SUS F 316H		X 5 CrNiMo 17-12		316S50	X6CrNiMo17-13
316 H?					03KH17N14M2	X 6 CrNiMo 17-12-03			
316 L	Z 2 CND 17-12	X2CrNiMo17-12-2	1.4404	SUS 316L		X 2 CrNiMo 17-12-03	23 48	316S11	X2CrNiMo17-12-2
316 L	Z 2 CND 17-13	X2CrNiMo 18-14-3	1.4435			X 2 CrNiMo 17-12-03	23 53	316S13	X2CrNiMo18-14-3
316 Ti	Z6 CNDT 17-12	X6CrNiMoTi17-12-2	1.4571		08KH17N13M2T 10KH17N13M2T	X 6 CrNiMoTi 17-12-03	23 50	320S18 320S31	X6CrNiMoTi17-12-2

USA AISI	France AFNOR	Germany DIN EN 10027-1	Germany DIN EN 10027-2	Japan JIS	Russia GOST	Spain UNE	Sweden SIS	UK BSI	European Union EN
316 Ti		X10CrNiMoTi18-12	1.4573		08KH16N13M2B	X 6 CrNiMoTi 17-12-03		320S33	X10CrNiMoTi18-12
317		X3CrNiMo18-12-3	1.4449	SUS 317			23 66	317S16	X3CrNiMo18-12-3
317 L	Z 2 CND 19-15	X2CrNiMo18-15-4	1.4438	SUS 317L			23 67	317S12	X2CrNiMo18-15-4
330	Z 20 NCS 33-16	X12NiCrSi35-16	1.4864	SUH 330	08KH18N10T				X12NiCrSi35-12
321		X6CrNiTi18-10	1.4541	SUS 321	12KH18N10T	X 6 CrNiTi 18-11	23 37	321S12	X6CrNiTi18-10
321(H)	Z 6 CNT 18-10	X8CrNiTi18-10	1.4878	SUS 321				321 S31	
329		X3CrNiMoN27-5-2	1.4460	SUS 329J1	08KH18N12B		23 24		X3CrNiMoN27-5-2
347	Z 6 CNNb 18-10	X6CrNiNb18-10	1.4550	SUS 347		X 6 CrNiNb 18-11	23 38	347S20 347S31	X6CrNiNb18-10
347 H?				SUS F 347H		X 7 CrNiNb 18-11			
904L	Z2NCDU 25-2	X2NiCrMoCu 25-20-5	1.4539				2562		X2NiCrMoCu 25-20-5

USA AISI	**France AFNOR**	**Germany**		**Japan JIS**	**Russia GOST**	**Spain UNE**	**Sweden SIS**	**UK BSI**	**European Union EN**
		DIN EN 10027-1	**DIN EN 10027-2**						
	Z12CNDV12-02	X12CrNiMoV12-3	1.4939						
		X15CrNiSi25-4	1.4821						X15CrNiSi25-
UNS31803		X2CrNiMoN22-5-3	1.4462					318S	X2CrNiMoN22-5-3
UNS32760	Z 3 CND 25-06Az	X2CrNiMoCuWN25-7-4	1.4501		12Kh13				
403	Z 12 C 13	X6Cr13	1.4000	SUS 403		X 6 Cr 13	23 01?	403S17	X6Cr13
405	Z 6 CA 13	X 6 CrAl 13	1.4002	SUS 405		X 6 CrAl 13	23 01	405S17	X 6 CrAl 13
	Z 8 CA 7	X 10 CrAl 7	1.4713		10Kh13SYu				X 10 CrAl 7
	Z 13 C 13	X 10 CrAl 13	1.4724		15Kh18SYu				
	Z 12 CAS 18	X 10 CrAl 18	1.4742						X 10 CrAl 18
409	Z 6 CT 12	X2CrTi12	1.4512	SUH 409				409S19	X2CrTi12
					12Kh13				
410		X12Cr13	1.4006	SUS 410				410S21	
420	Z 12 C 13 M	X 15 Cr 13	1.4024		08Kh13?	X 12 Cr 13?	23 02?		X15Cr13

Table 9.5. Selected Carbon Steel Designations

National Standard				Chemical Composition [Weight%] – Max.				
ASTM	**CZ**	**SS**	**EN Grade[32]**	**C**	**Mn**	**P**	**Cr**	**Mo**
105				0.35	1.05	0.040	--	--
106 Gr. A		1233-06	P235GH-TR1/2 (St 35.8)	0.17			--	--
106 Gr. B		1435-05	P265GH-TR1/2 (St 45.8)	0.30	1.06	0.048	0.30	0.12
106 Gr. C				0.35	1.20	0.050	0.40	0.15
53 Gr. A		1233-05	P235TR1/2 (St. 34.2)				--	--
53 Gr. B		1434-05	P265TR1/2 (St. 37.2)	0.30	1.20	0.05	--	--
	12022.1			0.20	0.60	0.04	0.25	--
334 WP22				0.15	0.60	0.04	2.60	1.13
335 P12			13 CrMo 44	0.15	0.61	0.045	1.25	0.65
335 P22			10 CrMo 9 10	0.15	0.60	0.030	2.60	1.13
B179 170.1			17 MnMoV 6 4 (WB 35)	0.21	1.80	0.035	--	0.55
			15 NiCuMoNb 5 S 1 (WB 36)	0.17		0.016	--	0.40
ASTM A 105 mainly used for forged fittings (elbows, flanges) ASTM A 106 is for high-temperature service (e.g. feedwater and steam piping) ASTM A 333 is for low temperature service ASTM A 335 is for high-temperature service (more resistant to FAC than A 106 steel)								

32. Designation per DIN Standard in parenthesis.

Table 9.6. ASTM, JIS and DIN Steel Designation

Steel Composition	ASTM Grade[33]	JIS Grade	European Standard EN Grade[34]
Carbon Steel	A120	SGP	10255 / S195(2440-ST33-1)[35]
Carbon Steel	A53-B	STPG38	10217-1/P235TR1 P235TR2 (1626-ST37)
Carbon Steel	A53-B	STPG42	-
Carbon Steel	A106-A	STPT38	10216-2/P235GHTC1 P235GH-TC2 (17175-St 35.8)
Carbon Steel	A106-B	STPT42	17175-St 45.8
Carbon Steel	A106-C	STPT49	-
Carbon Steel	A333 and A334-6	STPL39	-
3 1/2% Ni Steel	A333 and A334-3	STPL46	-
Carbon-Molybdenum Steel	A335-P1	STPA12	10216-2/16Mo3 (17175-15 Mo3)
1% Cr-1/2% Molybdenum Steel	A335-P12	STPA22	10216-2/13CrMo4-5 (17175-13CrMo44)
1 ¼% Cr-1/2% Molybdenum Steel	A335-P11	STPA23	-
2 ¼% Cr-1% Molybdenum Steel	A335-P22	STPA24	10216-2/10CrMoVNb9-1 (17175-10CrMo910)
5% Cr-1/2% Molybdenum Steel	A335-P5	STPA25	-
7% Cr-1/2% Molybdenum Steel	A335-P7	-	-
9% Cr-1% Molybdenum Steel	A335-P9	STPA26	-

33. TP stands for tube or piping

34. DIN Standard designation in parenthesis.

35. Norm DIN 2440 was for threaded tubing. The norm EN 10255 is for "Non-Alloy steel tubes suitable for welding, threading and other joining methods"

Steel Composition	ASTM Grade[33]	JIS Grade	European Standard EN Grade[34]
18%Cr -8% Ni Steel	A312-TP304	SUS304TP	10216-5/X5CrNi18-10 (17440-X5CrNi189)
18%Cr -8% Ni(0.04-0.10)% C Steel	A312-TP304H	SUS304HTP	-
18%Cr -8% Ni - 0.035% C Steel	A312-TP304L	SUS304LTP	10215-5/X2CrNi19-11 (17440-X2CrNi189)
22%Cr - 12% Ni Steel	A312-TP309	SUS309STP	-
25%Cr - 20% Ni Steel	A312-TP310	SUS310STP	-
25%Cr - 8% Ni-Cb+Ta Steel	A312-TP347	SUS347TP	10216-5/X6CrNiNb18-1 (17440-X10CrNiNb189)
18%Cr -8% Ni-Mo Steel	A312-TP316	SUS316TP	10216-5/X5CrNiMo17-12-2, X3CrNiMo17-13-3 (17440-X5CrNiMo1810)
18%Cr -8% Ni-Mo-(0.04-0.10)% C Steel	A312-TP316H	SUS316HTP	-
18%Cr -8% Ni-Mo-0.035% C Steel	A312-TP316L	SUS316LTP	10216-5/X2CrNiMo18-14-3 (17440-X2CrNiMo1810)
18%Cr -8% Ni-Ti Steel	A312-TP321	SUS321TP	10216-5/X6CrNiTi18-10 (17440-X10CrNiMo189)
18%Cr -8% Ni-Ti-(0.04-0.10)% C Steel	A312-TP321H	SUS321HTP	-
18%Cr -8% Ni-Cb+Ta-(0.04-0.10)% C Steel	A312-TP347H	SUS347HTP	-

Table 9.7. Plant System Cross-Reference Table

CODAP Generic1	Description	Czech Republic	France	Germany (7)		Sweden
				AKZ	KKS	
ADS	BWR Primary Depressurisation System (BWR)	--	--	TK, RA		314
AFW	Auxiliary Feedwater System		ASG	RQ		327
CC	Component Cooling Water System	TF	RRI	TF	LA	711/712
COND	Condensate System			RM, RN	LC	414/430 (4)
CRD	Control Rod Drive (Insert/Removal/Crud Removal)	--	RGL			354
CS	Containment Spray System	TQ	EAS			322
CVC	Chemical & Volume Control System (PWR)		RCV	TA, TC,	KB	334
CW	Circulating Water System / Intake Cooling Water					443
EHC	Electro Hydraulic Control System					442
EXT	Steam Extraction System					419/423
FPS	Fire Protection Water System	C-52	JPx			762
FW	Main Feedwater System		ARE	RL	LA	312/415 (5)
HPCS	High Pressure Core Spray (BWR)	--	--	TJ		--
HPSI	High Pressure Safety Injection (PWR)	TJ	RIS	TH	JN	--
IA	Instrument Air System	US				484
LPCS	Low Pressure Core Spray (BWR)	--	--	TK, TM		323
LPSI	Low Pressure Safety Injection (PWR)	TH	RIS	TH	JN	--
MS	Main Steam System		VVP	RA	LB	311/411 (6)
MSR	Moisture Separator Reheater System			RB	LB	422
RCS	Reactor Coolant System (PWR)		RCP	YA, YB,	JA, JE	313
RHR	Residual Heat Removal System	(2)	RRA	TH	JN	321
RR	Reactor Recirculation System (BWR)	--	--			313
RPV-HC	RPV Head Cooling System (BWR)	--	--	TC		326
RVLIS	Reactor Vessel Level Indication System (BWR)	--	--			536
RWCU	Reactor Water Cleanup System (BWR)	--	--	TC	KB	331

CODAP Generic1	Description	Czech Republic	France	Germany (7)		Sweden
				AKZ	KKS	
SA	Service Air System	TL		TL	KL	753
SFC	Spent Fuel Pool Cooling System	TG	PTR	TG	FA	324
S/G Blowdown	Steam Generator Blowdown System (PWR)		APG	RS	LA	337
SLC	Standby Liquid Control System (BWR)	--	--			351
SW	Service Water System (3)	VF	SEC	VE	PE	712/715

Notes:
See IEEE Std 805-1984 (IEEE Recommended Practice for System Identification in Nuclear Power Plants and Related Facilities) for information on system boundary definitions and system descriptions.
No dedicated RHR system in WWER-440 (decay heat removal is through natural circulation)
It is common practice in the US to use different system IDs for safety-related and non-safety related SW systems; e.g. ESW vs. PSW, or SX vs. WS, respectively for SX for Code Class 3 piping and non-Code piping
414 for F1/F2/R1/R2/R3/R4 and 430 for O1/O2/O3
312 for O1/O2/O3 and 415 for F1/F2/R1/R2/R3/R4. Also note that 312 is the designation for steam generators in Ringhals-2/3/4
311 for O1/O2/O3 411 for F1/F2/R1/R2/R3/R4
AKZ = Anlagen Kennzeichnungs System, KKS = Kraftwerk Kennzeichnungs System.

Table 9.8. Piping Safety Class Cross Reference Table[36]

USA / ASME Section III[37]		**Canada (CSA N285.0-95)**		**Czech Republic (Regulation 214/1997 Sb)**		**France (RRC-P 900 R.4)**		**Germany (KTA 3201/3211)**		**Switzerland (ENSI-G01/d)**	
Class	Definition	Class	Definition	Class	Definition	Class	Definition	Class	Definition	Class	Definition
1	Piping that forms the reactor coolant pressure boundary (RCPB). That is, all piping components that are part of the reactor coolant system RCS), or connected to the RCS up to and including any or all of the following: a) the outermost primary containment isolation valve in piping that penetrates the primary containment; b) the second of two valves normally closed during normal reactor operation in system piping	1	Pipe diameter > DN20; Sections of systems, or systems connected thereto, which contain fluid that directly transports heat from nuclear fuel, and whose failure would cause a loss of coolant accident as defined in the safety report.	1	Equipment of the RCPB, except equipment whose rupture would result in a leakage of a magnitude within the capacity of the normal coolant make-up system.	1	RCS and its connecting lines with inside diameter greater than 10.6 mm for water or greater than 21.9 mm for steam, up to and including the two reactor coolant isolation valves. class one piping also includes the pressurizer letdown line up to and including the relief and safety valves.	1	For PWRs: a) RPV; b) Primary side of the S/Gs, the secondary shell of the S/Gs incl. the FW-inlet and MS-exit nozzles up to the pipe connecting welds (excl. small-diameter fittings); c) pressuriser; d) RCP casing; e) connecting pipes between the above components and the valve casings of any type contained in the piping system; f) pipes branching off from the above	SK-1	Pressure retaining boundary of the reactor cooling system up to the second isolation valve or safety valve, including small-diameter piping and pressure retaining parts of instrumentation.

36. This table was prepared by the OPDE-PRG in 2005. It is reproduced from the OPDE/CODAP Coding Guideline/

37. The ASME III classification is explained in U.S. NRC Regulatory Guide R.G 1.26 (Revision 4, 2007).

USA / ASME Section III[37]		Canada (CSA N285.0-95)		Czech Republic (Regulation 214/1997 Sb)		France (RRC-P 900 R.4)		Germany (KTA 3201/3211)		Switzerland (ENSI-G01/d)	
Class	Definition	Class	Definition	Class	Definition	Class	Definition	Class	Definition	Class	Definition
	that does not penetrate primary containment; or, c) the RCS safety and relief valves.								components and their connecting pipes including the valve bodies up to and including the first shut-off valve; g) control rod drives and the in-core instrumentation. For BWR: a) RPV; b) piping connected to the RPV including the valve bodies incl. first shut-off valve, pipework penetrating the containment shell incl. the last shut-off valve located outside the containment shell; c) control rod drive and in-core instrumentation.		
2	Systems or portions of systems	2	Pipe diameter > DN20; Sections	2	a) components creating the	2	Equipment and components of	2 & 3	Piping and piping components that are not	SK-2	a) reactor cooling and

USA / ASME Section III[37]		Canada (CSA N285.0-95)		Czech Republic (Regulation 214/1997 Sb)		France (RRC-P 900 R.4)		Germany (KTA 3201/3211)		Switzerland (ENSI-G01/d)	
Class	Definition	Class	Definition	Class	Definition	Class	Definition	Class	Definition	Class	Definition
	important to safety that are designed for: a) emergency core cooling; b) post-accident containment heat removal, or c) post-accident fission product removal.		of process systems that penetrate the containment structure and form part of the containment boundary.		RCPB, that are not ranked as class one; b) components for the reactor shutdown during the abnormal operation during the states which could lead to the accident conditions, and for the reactor shutdown with the aim to mitigate the consequences of accident conditions; c) components necessary to retain the coolant inventory sufficient for the core cooling during the accident conditions when no damage of the reactor coolant pressure system has occurred, and after these conditions;		systems carrying reactor coolant that are not safety class one and to equipment and components required to ensure containment of radioactivity in the event of a loss of coolant accident. This includes: a) equipment and components that are not safety class one; b) main equipment and components of the following systems: RHRS, CVCS, ECCS, CSS; c) equipment and components that constitute the third barrier: the reactor containment and the associated isolation		part of the RCPB but have a certain significance with respect to reactor safety: a) The component is required for the mitigation of DBAs with respect to shut down, long-term maintenance of subcriticality, and decay heat removal. b) Requirements regarding components of systems which only indirectly serve in residual heat removal – these are the non-radioactivity retaining closed cooling water systems and service water systems – shall be specified on a plant-specific basis taking the design redundancy (e.g. redundancy,		emergency cooling; b) residual heat removal from reactor, containment, and steam generators; c) cooling of RCS in the cold depressurised state; d) all reactor shut down functions and functions to maintain subcriticality; e) safety functions of primary containment systems; f) components to maintain subcriticality in the fuel element storage; g) BWR: Main steam and feed water line between

USA / ASME Section III[37]		Canada (CSA N285.0-95)		Czech Republic (Regulation 214/1997 Sb)		France (RRC-P 900 R.4)		Germany (KTA 3201/3211)		Switzerland (ENSI-G01/d)	
Class	Definition	Class	Definition	Class	Definition	Class	Definition	Class	Definition	Class	Definition
					d) components necessary to remove the core heat, when the reactor coolant pressure system is damaged, with the aim to limit the fuel damage; e) components of the residual heat removal system during the normal and abnormal operation and under the accident conditions, without the loss of the RCPB's integrity; f) components necessary for the prevention of radioactive leakage from the containment during the accident and post-accident conditions; g) components necessary to limit		systems, portions of secondary systems inside the reactor building up to and including the first isolation valve located outside the reactor building, containment hydrogen control system, equipment and components of the in-core instrumentation system up to and including the manual isolation valve.		diversity) into consideration. c) Large energies are released in case of failure of the plant component and no mitigating measures such as structural measures, spatial separation or other safety measures are available to keep the effects of the failure to an acceptable limit with respect to nuclear safety. d) A failure of the plant component could either directly or indirectly through a chain of assumed sequential events, lead to a DBA. e) Systems and components to which none of criteria a) through c) apply, the failure of which, however, would		second isolation valve and next remote control isolation valve; h) PWR: Secondary side of steam generator up to isolation valve outside primary containment; i) components that could cause a dose limit violation according to Article 94 Paragraph 4 of Radiation Protection Ordinance SR814.501.

USA / ASME Section III[37]		Canada (CSA N285.0-95)		Czech Republic (Regulation 214/1997 Sb)		France (RRC-P 900 R.4)		Germany (KTA 3201/3211)		Switzerland (ENSI-G01/d)	
Class	Definition	Class	Definition	Class	Definition	Class	Definition	Class	Definition	Class	Definition
					the ionising radiation penetration outside the containment, during and after the accident conditions; h) components necessary to accomplish the safety functions for the power supply or for the control of other components ranked as the safety class two.				lead to major plant internal damage.		
3	Cooling water and auxiliary feedwater systems or portions of these systems important to safety that are designed for: a) emergency core cooling; b) post-accident containment heat removal; c) post-accident containment atmosphere cleanup, or	3	Pipe diameter > DN20; Sections of systems, not classified as class one or two, that contain radioactive substances with a tritium concentration exceeding 0.4 TBq/kg (0.01 Ci/g), or an energy-weighted activity concentration of	3	a) components necessary to prevent the unallowable transient processes connected with the reactivity changes; b) components necessary to maintain the nuclear reactor in the safe shutdown conditions; c) components necessary to maintain sufficient	3	Safety Class 3 includes: a) CVCS equipment and components required for the purification of the reactor coolant water and the boron makeup system and equipment; b) S/G AFWS equipment and		See “2 & 3” above	SK-3	a) systems for leakage and seal water in the primary containment; b) cooling of fuel element storage pool; c) systems for gaseous radioactive media; d) RWCU of BWR (typically SK-1 and 3),

USA / ASME Section III[37]		Canada (CSA N285.0-95)		Czech Republic (Regulation 214/1997 Sb)		France (RRC-P 900 R.4)		Germany (KTA 3201/3211)		Switzerland (ENSI-G01/d)	
Class	Definition	Class	Definition	Class	Definition	Class	Definition	Class	Definition	Class	Definition
	d) residual heat removal from reactor and from the spent fuel storage pool (including primary and secondary cooling systems). Portions of these systems that are required for their safety functions and that: a) do not operate during any mode of normal reactor operation and b) cannot be tested adequately should be classified as class two.		radionuclides exceeding that of 0.4 TBg/kg of Tritium.		reactor coolant inventory for the core cooling during the normal and abnormal operation; d) components necessary to remove heat from the safety systems to the first accumulating volume, which is sufficient from the viewpoint of performance of safety functions; e) components necessary to maintain the radiation exposure of population and of nuclear installation personnel below the established limits, during the accident conditions connected with the leakage of radioactive substances and ionizing radiation from the sources		components located outside reactor containment; c) CCWS and ESWS equipment and components; d) reactor cavity and spent fuel pit cooling and treatment system equipment and components; e) radioactive waste treatment systems equipment and components whose failure could cause release of radioactive gases normally stored for decay.				CVCS of PWR (typically SK-2 and 3); e) auxiliary systems for SK-1 through 3 components and 1E classified electrical equipment; f) systems for accident mitigation.

USA / ASME Section III[37]		Canada (CSA N285.0-95)		Czech Republic (Regulation 214/1997 Sb)		France (RRC-P 900 R.4)		Germany (KTA 3201/3211)		Switzerland (ENSI-G01/d)	
Class	Definition	Class	Definition	Class	Definition	Class	Definition	Class	Definition	Class	Definition
					located outside the containment, and after such conditions; f) components requisite to maintain such environmental conditions inside the nuclear installation that are necessary for the operation of safety systems and for the access of the personnel to perform the important activities related to safety; g) components necessary to prevent the radioactive leakage from the irradiated fuel that is transported or stored within the nuclear installation, out of the core cooling system during all states of normal and abnormal operation;						

USA / ASME Section III[37]		Canada (CSA N285.0-95)		Czech Republic (Regulation 214/1997 Sb)		France (RRC-P 900 R.4)		Germany (KTA 3201/3211)		Switzerland (ENSI-G01/d)	
Class	Definition	Class	Definition	Class	Definition	Class	Definition	Class	Definition	Class	Definition
					h) components necessary to remove fission heat from the irradiated fuel stored within the nuclear installation, out of the core cooling system; i) components requisite to maintain sufficient sub-criticality of fuel stored within the nuclear installation, out of the core cooling system; j) components requisite to limit the effluents or the leakage of solid, liquid or gaseous radioactive substances and ionizing radiation below the established limiting values during all states of normal and abnormal operation; k) components requisite to						

USA / ASME Section III[37]		Canada (CSA N285.0-95)		Czech Republic (Regulation 214/1997 Sb)		France (RRC-P 900 R.4)		Germany (KTA 3201/3211)		Switzerland (ENSI-G01/d)	
Class	Definition	Class	Definition	Class	Definition	Class	Definition	Class	Definition	Class	Definition
					perform the safety functions related to the power supply or to the control of other components ranked as the safety class 3; l) components requisite to perform the safety functions for the assurance of functional capability of other components ranked as the safety classes 1, 2 and 3, that are not related to the control or to the power supply; m) components necessary for prevention or mitigation of the consequences of failures of the other components or constructions of safety systems ranked as the safety classes one, two and three.						

10. Appendix
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11. Appendix
Glossary of technical terms

Austenitic Alloy Steel. Also high-alloy steels with the main alloying elements being chromium (Cr) and nickel (Ni). Some high-alloy steels include niobium (Nb) to improve welding properties, or titanium (Ti) to prevent intergranular corrosion and weld decay.

Below Ground Piping. See “underground piping” below.

BONNA® Pipe. A thin steel pipe embedded in reinforced concrete. It has rebar or a heavy wire mesh embedded in the OD concrete.

Buried Piping. Piping that is below grade and in direct contact with soil. Buried piping is provided with corrosion protection such as coating and cathodic protection.

Cathodic Protection (CP). A corrosion protection technique in which the potential difference is applied to buried piping from an external power source or a more anodic material (sacrificial anode) for the purpose of making the piping behave in a cathodic manner. Through the use of CP, the corrosion rate is normally reduced to an acceptable level.

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 PRA model quantification. For piping components, the component boundary is established through degradation mechanism evaluations (see below).

Concrete Encased Piping (CEP). Below ground piping that is embedded in concrete. The piping is not easily extracted nor is the interior pipe surface readily accessible for inspection. The CEP category also includes piping recessed in plant building floors.

Corrosion Fatigue. The behaviour of materials under cyclic loading conditions is commonly considered as consisting of two broad categories of material properties. One category relates to cyclic life for the formation of a fatigue crack in a smooth test specimen, the so-called S-N fatigue properties. The second relates to the growth of a pre-existing crack. Laboratory test have shown that LWR coolant water can have a detrimental effect on both S-N fatigue properties and fatigue crack growth.

Crevice Corrosion. Crevice corrosion occurs in a wetted or buried environment when a crevice or area of stagnant or low flow exists that allows a corrosive environment to develop in a component. It occurs most frequently in joints and connections, or points of contact between metals and nonmetals, such as gasket surfaces, lap joints, and under bolt heads. Carbon steel, cast iron, low alloy steels, stainless steel, copper, and nickel base alloys are all susceptible to crevice corrosion. Steel can be subject to crevice corrosion in some cases after lining/cladding degradation.

Cumulative Usage Factor (CUF). The cumulative usage factor (CUF) is the sum of the individual usage factors (UFs; see below), and ASME Code Section III requires that the CUF at each location must not exceed one.

Cured-in-Place-Pipe (CIPP). A BP temporary repair method. A resin-saturated felt tube made of polyester, fiberglass cloth or a number of other materials suitable for resin impregnation, is inverted or pulled into a damaged pipe. It is usually done from the upstream access point (manhole or excavation).

Damage Mechanism. Excessive internal or external loading conditions that cause physical damage to a component pressure boundary. Pressure shocks from a water hammer might damage pipe hangers and snubbers, or distort a piping section.

Degradation Mechanism. Phenomena or processes that attack (wear, erode, crack, etc.) the pressure-retaining material over time and might result in a reduction of component pressure boundary integrity. It should be noted that damage mechanisms (e.g. a sudden hydraulic pressure transient) and degradation mechanisms could interact to cause major, catastrophic passive component failures.

Degradation Mechanism Evaluation. The identification of degradation mechanisms in a pipe segment by comparing actual piping design and operating conditions to a well-defined set of material and environmental attributes. The evaluation considers plant-specific service experience involving cracking and leakage.

Discontinuity. A lack of continuity or cohesion; an interruption in the normal physical structure of material or a product.

Double-Walled Pipe. A double-walled pipe is a secondary contained piping system. It is a pipe-within-a-pipe, or encased in an outer covering, with an annulus (interstitial space) between the two diameters. The inner pipe is the primary or carrier pipe and the outer pipe is called the secondary or containment pipe.

*Enhanced Visual Examination (EVT-1).*The EVT-1 method is intended for the visual examination of surface breaking flaws. Any visual inspection for cracking requires a reasonable expectation that the flaw length and crack mouth opening displacement meet the resolution requirements of the observation technique. The EVT-1 specification augments the VT-i requirements to provide more rigorous inspection standards for stress corrosion cracking. EVT-1 is also conducted in accordance with the requirements described for visual examination (i.e. VT-1) with additional requirements (such as camera scanning speed). Any recommendation for EVT-1 inspection will require additional analysis to establish flaw-tolerance criteria, which must take into account potential embrittlement due to thermal aging or neutron irradiation. Acceptance criteria methodologies to support plant-specific augmented examinations are documented in WCAP-17096-NP[39].

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 misdiagnosed 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 decay heat removal and charging systems.

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 OPDE database the term "erosion/corrosion" applies only to moderate energy carbon steel piping (e.g. raw water piping).

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39. Westinghouse Electric Company LLC, Reactor Internals Acceptance Criteria Methodology and Data Requirements, WCAP-17096-NP, Cranberry Township, PA, December 2009.

Ferritic Alloy Steel. Also low-alloy steels, which have a carbon content less than 0.2% and contain a total of < 12% alloying elements (e.g., Cr, MN, Mo, Ni).

Fillet Weld. A weld of approximately triangular cross section joining two surfaces approximately at right angles to each other in a lap joint, tee joint, corner joint, or socket weld.

Flaw. An imperfection or unintentional discontinuity that is detectable by non-destructive examination (NDE).

Flaw Aspect Ratio. Ratio of the length of the deepest crack to the depth of the deepest crack.

Flow Accelerated (or Assisted) Corrosion (FAC). EPRI defines FAC as "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 single phase and in two phase regions. According to EPRI, the cause of FAC is a specific set of water chemistry conditions (e.g. pH, level of dissolved oxygen), and absent a mechanical contribution to the dissolution of the normally protective iron oxide (magnetite) layer on the inside pipe wall.

Full Structural Weld Overlay (FSWOL). A structural reinforcement and stress corrosion cracking (SCC) mitigation technique through application of a SCC-resistant material layer around the entire circumference of the treated weldment. The minimum acceptable FSWOL thickness is 1/3 the original pipe wall thickness. The minimum length is $0.75\sqrt{(R \times t)}$ on either side of the dissimilar metal weld to be treated, where R is the outer radius of the item and t is the nominal thickness of the item.

General Corrosion. An approximately uniform wastage of a surface of a component, through chemical or electrochemical action, free of deep pits or cracks.

High Energy Piping. A piping system for which the maximum operating temperature exceeds 200 ºF (94.33 ºC) or the maximum operating pressure exceeds 275 psig (1.896 MPa).

Holiday in Pipe Coating. A holiday is a hole or void in the coating film which exposes the buried piping to corrosion.

Hydrostatic Pressure Test. A pressure test conducted during a plant or system shutdown at a pressure above nominal operating pressure or system pressure for which overpressure protection is provided.

Inclusion. An "inclusion" is a non-metallic impurity such as slag, oxide, and sulphide that is present in the original ingot. During rolling of billets into bar stock, impurities are rolled in a lengthwise direction. These direction-oriented inclusions in the finished product are generally referred to as non-metallic inclusions or "stringers". These stringers may be surface or subsurface and are usually short in length and parallel to the grain flow.

Indication. The definition of the term "indication" as it applies to NDE is: "A response or evidence of a response disclosed through NDE that requires further evaluation to determine its true significance."

Intergranular Stress Corrosion Cracking (IGSCC). IGSCC is associated in particular with a sensitised material (e.g. sensitised austenitic stainless steels are susceptible to IGSCC in an oxidizing environment). Sensitisation of unstabilised austenitic stainless steels is characterised by a precipitation of a network of chromium carbides with depletion of chromium at the grain boundaries, making these boundaries vulnerable to corrosive attack.

Irradiation Assisted Stress Corrosion Cracking (IASCC). IASCC refers to intergranular cracking of materials exposed to ionising radiation. As with SCC, IASCC requires stress, aggressive environment and a susceptible material. However, in the case of IASCC, a normally non-susceptible material is rendered susceptible by exposure to neutron irradiation. IASCC is a plausible ageing mechanism, in particular for PWR internal components (e.g. baffle bolts).

In-service Pressure Test. A system pressure test conducted to perform visual examination VT-2 while the system is in service under operating pressure.

Isometric Drawing. In the context of piping design, an isometric drawing is a three-dimensional representation of a piping system showing the length, depth and width in a single view. Piping isometrics are often used by designers prior to a stress analysis and are also used by draftsmen to produce shop fabrication spool drawings. In-service inspection (ISI) engineers use isometric drawings to define and identify ISI locations.

JRC Operating Experience Clearinghouse (CE-OEF). Located in Petten, the Netherlands, the Clearinghouse gathers nuclear safety experts performing the following technical tasks in support to the EU member states:

- "Topical Studies" providing in-depth assessment of either particularly significant events or either families of events. These studies are drafted by experts on the topic and based on an analysis of usually hundreds of event reports.
- Trend analysis of events in order to identify priority areas.
- Improvement of the quality of event reports submitted by the EU Member States to the international reporting system jointly operated by the OECD-NEA and the IAEA.
- Reporting every three months the main events having occurred in NPPs.
- Database: a European central OE repository being developed in order to ensure long term storage of OE and to facilitate information retrieval.
- Further to these activities, the EU clearinghouse is participating to several international cooperation projects on OE, mainly through the IAEA and the OECD-NEA working groups.
- https://clearinghouse-oef.jrc.ec.europa.eu/

Latent Failure. A degraded material condition that may lie dormant for a long period before leading to a visible flaw (e.g. through-wall crack, active leakage).

Leak Detection System. Instrumentation and controls that use various temperature, pressure, level and flow sensors to detect water and steam leakages in selected reactor systems and to initiate annunciation and provide isolation signal (in certain cases) to limit leakage from the reactor coolant pressure boundary when limiting leakage conditions exists.

Leakage Pressure Test. A system pressure test conducted during operation at nominal operating pressure, or when pressurised to nominal operating pressure and temperature.

Limiting Condition for Operation (LCO). According to the Technical Specifications[40], a LCO is the lowest functional capability or performance level of a piece of equipment

40. "Betriebshandbuch" in German.

required for safe operation of a nuclear plant. When a LCO cannot be met, the reactor must be shut down or the licensee must follow any remedial action permitted by the Technical Specifications until the condition can be met.

Liquid Penetrant Examination. Liquid Penetrant Examination (LPT) uses liquids to detect cracks in materials. In the mid and late 1930's, Robert and Joseph Switzer worked with processes incorporating visible coloured dyes in the penetrant to give better contrast. In 1941 they introduced processes using fluorescent dyes which, when viewed under a black light, produced contrasts superior to those obtainable with the visible dyes. The fluorescent method was quickly accepted by the military for aircraft part examination. Since then, the use of both colour-contrast and fluorescent penetrants has spread to practically all fields of manufacturing, and new and improved PT products are constantly being developed.

Low-Frequency Electromagnetic Testing (LFET). This technique measures the changes in electro-magnetic fields while the scanner passes over the metal. Defects and corrosion maps are calculated and video displayed in real-time, high resolution, 3-D colour graphics that can be saved for further data analysis or permanent record archiving Very low frequency magnetic signals are not affected by iron oxide or any non-magnetic surface deposits which allows for accurate testing on base metals in piping.

LTA-NDE. As used in this report the term “Less-Than-Adequate NDE” implies that deficiencies in the implementation of a qualified NDE process have contributed to a reportable or rejectable flaw remaining undetected for a certain period.

LTA-RIM. In this report, LTA-RIM is defined as events where degradation has progressed beyond acceptable limits in systems, structures or components (SSCs) that have a RIM program. These LTA-RIM events have some safety significance. In this topical report the LTA-RIM definition is broadened to also include events where a RIM program has resulted in a “false positive”; that is, it has identified degradation that either didn’t exist or was not close to violating acceptance criteria. While such events needlessly expend resources and could be considered LTA-RIM from an economic perspective, they do not have any safety significance.

Mechanical Stress Improvement Process (MSIP®). A patented process that was invented, developed and first used in 1986 by NuVision Engineering Inc. for mitigating stress corrosion cracking in nuclear plant weldments. MSIP® works by using a hydraulically operated clamp which contracts the pipe on one side of the weldment. A typical tool design consists of a specially designed hydraulic box press for bringing the clamp halves together. By contracting the pipe on one side of the weldment, the residual tensile stresses are replaced with compressive stresses.

Moderate Energy Piping. A piping system for which the maximum operating temperature is less than 200 ºF (94.33 ºC) or the maximum operating pressure is less than 275 psig (1.896 MPa).

NDE Qualification. In the context of NDE, qualification includes technical justification, which involves assembling all the supporting evidence for inspection capability (results of capability evaluation exercises, feedback from site experience, applicable and validated theoretical models, physical reasoning), and may include practical trials using deliberately defective test pieces.

Nondestructive Examination (NDE). An examination by the visual, surface, or volumetric method.

Operating Agent. According to the CODAP operating procedures, to assure consistency of the 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). 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.

Optimized Weld Overlay (OWOL). A subset of the full structural weld overlay (FSWOL) process. It has been developed for larger geometries (e.g. RCS Hot and Cold Leg nozzles) where FSWOL application becomes too time consuming for a typical refuelling outage. The optimised weld overlay thickness is less than that of a full structural weld overlay in order allow completion in the time available in a typical refuelling outage for the larger geometries.

Pattern Recognition. Pattern recognition is applied to the interpretation of event reports with scarce (or unclear) details on failure location and root cause. In the context of event data analysis, "pattern recognition" is a structured process of determining the cause of degradation using known failure patterns for similar piping systems. Data analysis and classification builds on the retrieval of data on similar events, and performing a comparative analysis to determine the nature of apparent similarities between industry data and the specific event.

Pipe Schedule Designation. The schedule number (SN) is defined as SN = 1000 × (P/SE), where P is operating pressure in lb/in^2 and SE is allowable stress range multiplied by joint efficiency in lb/in^2. Most US pipe failure reports include pipe schedule information.

Primary Water Stress Corrosion Cracking (PWSCC). PWSCC is a form of IGSCC and is defined as intergranular cracking in primary water within specification limits (i.e. no need for additional aggressive species – for example, IGSCC of Alloy 600 in primary water).

Probability of Detection (POD). It is the probability that a flaw of a certain size will be detected and it is conditional on factors such as wall thickness, NDE personnel qualifications, and flaw orientation.

Radiographic Examination. A non-destructive testing (NDE) method of inspecting materials for hidden flaws by using the ability of short wavelength electromagnetic radiation (high energy photons) to penetrate various materials.

Reliability and Integrity Management (RIM). Those aspects of the plant design and operational phase that are applied to provide an appropriate level of reliability of SSCs and a continuing assurance over the life of the plant that such reliability is maintained.

Root Mean Square (RMS) Evaluation. NDE qualifications include the use of an ultrasonic sizing procedure which should be developed and qualified for equipment, technique, and sizing examination personnel. At least ten flawed specimens should be used in the performance demonstration. A Root Mean Square (RMS) evaluation should be used to demonstrate adequate sizing performance. This is given by the formula:

$$RMS = \sqrt{(T-U)^2/N}$$

Where

T = Truth or actual flaw depth

U = Ultrasonic flaw depth estimate

N = Number of test specimens or flaws sized

Acceptable flaw sizing performance demonstration is achieved when the RMS is 12.5% or less. This is comparable to the Appendix VIII criteria proposed in ASME Code Section XI. Accordingly, it was demonstrated that at an RMS of 15% or less, acceptable sizing performance is achieved comparable to the current EPRI NDE centre intergranular stress corrosion cracking (IGSCC), sizing programme. The advanced ultrasonic sizing techniques described in this handbook have been developed in accordance with recommended guidelines of the EPRI NDE centre ultrasonic planar flaw sizing of IGSCC. Variations or modifications of the techniques have been incorporated to improve accuracy of flaw depth sizing of stress corrosion, thermal fatigue and mechanical fatigue cracks.

Root Cause Analysis (RCA). RCA is a collective term that describes a wide range of systematic approaches and techniques used to uncover causes of problems. Root cause is a factor that causes a non-conformance (e.g. structural degradation or failure) and should be permanently eliminated through process improvement.

SAFT. **S**ynthetic **A**perture **F**ocusing **T**echnique is a signal processing technique which takes advantage of the movement of a small conventional transducer to simulate, in effect, a phased array that is extremely long. This allows high resolution at long range, with relatively small transducers. SAFT in ultrasonics has been around for over twenty years but the amount of processing required has meant that it has had to wait for developments in computing technology before it can be readily applied. Phased array techniques have developed at a faster pace than SAFT, however.

Seal Weld. A fillet weld used on a pipe joint primarily to obtain fluid tightness as opposed to mechanical strength. It is usually used in connection with a threaded joint.

Selective Leaching. Also referred to as dealloying, demetalification, parting and selective corrosion, is a corrosion type in some solid solution alloys, when in suitable conditions a component of the alloys is preferentially leached from the material. The less noble metal is removed from the alloy by a microscopic-scale galvanic corrosion mechanism. The most susceptible alloys are the ones containing metals with high distance between each other in the galvanic series, e.g. copper and zinc in brass.

Socket Weld. Fillet-type weld used to join pipe to valves and fittings or to other sections of pipe. Generally used for piping whose nominal diameter is 50 mm or smaller.

Strain Induced Corrosion Cracking (SICC). SICC is used to refer to those corrosion situations in which the presence of localised dynamic straining is essential for crack formation (i.e. initiation and propagation) to occur, but in which cyclic loading is either absent or restricted to a very low number of infrequent events. SICC has been observed in particular in pressurised components in German nuclear power plants made of higher-strength carbon steel and low-alloy steel.

Stress Corrosion Cracking (SCC). SCC is a localised non-ductile failure which occurs only under the combination of three factors: 1) tensile stress, 2) aggressive environment, and 3) susceptible material. The SCC failure mode can be intergranular (IGSCC), or transgranular (TGSCC). In a nuclear power plant operating environment, primary water SCC (PWSCC), and irradiation assisted SCC (IASCC) are also defined.

Structured Query Language (SQL). A standard computer **language** for relational database management and data manipulation. **SQL** is used to **query**, insert, update and modify data.

Sweepolet (Weldolet). Tradename for a contoured, integrally reinforced, butt-welded branch connection.

TECHITE® Pipe. Fiberglass (or Fiber Reinforced Polymer) reinforced mortar pipe. This type of piping has found very limited use in cooling tower blowdown/discharge applications. This material can be affected by the environment, becoming brittle or soft, and breaking or leaking.

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.

Transgranular Stress Corrosion Cracking (TGSCC). TGSCC is caused by aggressive chemical species especially if coupled with oxygen and combined with high stresses.

Tritium. Tritium is a naturally occurring radioactive form of hydrogen that is produced in the atmosphere when cosmic rays collide with air molecules. As a result, tritium is found in very small or trace amounts in groundwater throughout the world. It is also a byproduct of the production of electricity by nuclear power plants. Tritium emits a weak form of radiation, a low-energy beta particle similar to an electron. The tritium radiation does not travel very far in air and cannot penetrate the skin.

Tritium in Nuclear Power Plants. Most of the tritium produced in nuclear power plants stems from a chemical, known as boron, absorbing neutrons from the plant's chain reaction. Nuclear reactors use boron, a good neutron absorber, to help control the chain reaction. Toward that end, boron either is added directly to the coolant water or is used in the control rods to control the chain reaction. Much smaller amounts of tritium can also be produced from the splitting of Uranium-235 in the reactor core, or when other chemicals (e.g. lithium or heavy water) in the coolant water absorb neutrons. Like normal hydrogen, tritium can bond with oxygen to form water. When this happens, the resulting "tritiated" water is radioactive. Tritiated water (not to be confused with heavy water) is chemically identical to normal water and the tritium cannot be filtered out of the water.

Underground Piping. Piping that is below grade, but is contained within a tunnel or vault such that it is contact with air and is located where access for inspection is restricted.

Unified Numbering System (UNS). An alloy designation system in use in North America. It consists of a prefix letter and five digits designating a material composition. For example, a prefix of S indicates stainless steel, C indicates copper, brass or bronze alloys.

Usage Factor (UF). Cyclic loadings on a structural component occur because of changes in mechanical and thermal loadings as the system goes from one load set (e.g. pressure, temperature, moment, and force loading) to another. For each load set, an individual fatigue usage factor (UF) is determined by the ratio of the number of cycles anticipated during the lifetime of the component to the allowable cycles.

VT-1 Examination. A limited visual examination specific to ASME Section XI which is the observation of exposed surfaces of a part, component, or weld to determine its physical condition including such irregularities as cracks, wear, erosion, corrosion, or physical damage.

VT-2 Examination. Per ASME XI, a visual surface examination to locate evidence of leakage from pressure-retaining components.

VT-3 Examination. A limited visual examination specific to ASME Section XI which is the observation to determine the general mechanical and structural condition of components and their supports, such as the verification of clearances, settings, physical displacements, lose or missing parts, debris, corrosion, wear, erosion, or the loss of integrity at bolted or welded connections. The VT-3 examinations shall include examinations for conditions that could affect operability of functional adequacy of snubbers, and constant load and spring type supports. The VT-3 examination is intended to identify individual components with significant levels of existing degradation. As the VT-3 examination is not intended to detect the early stages of component cracking or other incipient degradation effects, it should not be used when failure of an individual component could threaten either plant safety or operational stability. The VT-3 examination may be appropriate for inspecting highly redundant components (such as baffle-edge bolts), where a single failure does not compromise the function or integrity of the critical assembly.

Visual Examination. The oldest and most commonly used NDE method is Visual Testing (VT), which may be defined as an examination of an object using the naked eye, alone or in conjunction with various magnifying devices, without changing, altering, or destroying the object being examined. Per ASME XI, there are three different VT methods; VT-1, VT-2 and VT-3.

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.

WEKO-SEAL®. A flexible rubber leak clamp that ensures a non-corrodible, bottle-tight seal around the full inside circumference of the pipe-joint area. The design incorporates a series of proprietary lip seals that create a leak proof fit on either side of the joint.

Weld Inlay. A mitigation technique defined as application of PWSCC-resistant material (Alloy 52/52M) to the inside diameter of a dissimilar metal weld that isolates the PWSCC-susceptible material (Alloy 82/182) from the primary reactor coolant.

Weldolet. The most common of all branch connections, and is welded onto a larger-diameter pipe. The ends are bevelled to facilitate this process, and therefore the "weldolet" is considered a butt-weld fitting. Weldolets are designed to minimise stress concentrations and provide integral reinforcement.