THE OECD/NEA CODAP PROJECT & ITS CONTRIBUTION TO PLANT AGING MANAGEMENT & PROBABILISTIC SAFETY ASSESSMENT

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Environmental degradation mechanisms have caused significant nuclear power plant operability challenges including forced reactor shutdowns and extended outages. Since the 1970s, research and development efforts have been devoted to better understand the underlying physical phenomena in order to mitigate re-occurrences and to the development of metallic passive component degradation mitigation programs that ensure the long-term structural integrity of piping pressure boundary components. With emphasis on probabilistic safety assessment (PSA) applications, this technical paper presents an overview of the objectives and results of the work performed by the OECD Nuclear Energy Agency CODAP Project Review Group (PRG) to establish a web-based SQL-database on passive reactor component degradation and failures.

I. CODAP ORIGIN & PROJECT HISTORY

Several OECD Member Countries have agreed to establish the OECD/NEA "Component Operational Experience, Degradation & Ageing Programme" (CODAP) to encourage multilateral co-operation in the collection and analysis of data relating to degradation and failure of metallic piping and non-piping metallic passive components in commercial nuclear power plants. The scope of the data collection includes service-induced wall thinning, part through-wall cracks, through-wall cracks with and without active leakage, and instances of significant degradation of metallic passive components, including piping components. The data collection covers the period 1970 to date. The Project is organised under the OECD/NEA Committee on the Safety of Nuclear Installations (CSNI).

CODAP is the continuation of the 2002–2011 "OECD/NEA Pipe Failure Data Exchange Project" (OPDE) (Ref. 1) and the 2006-2010 Stress Corrosion Cracking Working Group of the “OECD/NEA SCC and Cable Ageing project” (SCAP) (Ref. 2). OPDE was formally launched in May 2002. Upon completion of the 3rd Term (May 2011), the OPDE project was officially closed to be succeeded by CODAP. SCAP was enabled by a voluntary contribution from Japan. It was formally launched in June 2006 and officially closed with an international workshop held in Tokyo in May 2010 (Ref. 3). A majority of the member organizations of the two projects were the same, often being represented by the same person. In May 2011, thirteen countries signed the CODAP 1st Term agreement (Canada, Chinese Taipei, Czech Republic, Finland, France, Germany, Korea (Republic of), Japan, Slovak Republic, Spain, Sweden, Switzerland and United States of America) (Ref. 4). Currently in its 2nd Term (2015-2017), the project continues to collect and evaluate operating experience data including corrosion mechanisms acting on reactor components.

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

The Online Event Database includes over 4800 selected event records from 324 commercial nuclear power plants. The Online Knowledgebase includes country-specific collections of documents and supporting information sorted by degradation mechanisms based on the events in the Online Event Database. Data quality, including data validation requirements are documented in a Coding Guideline. Public domain work products in the form of Topical Reports are available for download on the OECD NEA website (http://www.oecd-nea.org/nsd/docs/indexcsni.html).

I.A. Origin

The CODAP international collaboration has its origins in the risk-informed piping reliability work performed and sponsored by the Swedish Nuclear Power Inspectorate (SKI, since 2008 the Swedish Radiation Safety Authority, SSM) in the early 1990s and in response to the so called 1992 "Barsebäck-2 strainer event." On July 28, 1992, a steam line pressure boundary breach occurred when a safety relief valve (SRV) inadvertently opened in Barsebäck-2 nuclear power plant, a third generation Swedish boiling water reactor (BWR) design. At the time of the event, the plant was returning to service after an annual refueling and maintenance outage. With the reactor at about 2% power and 3.2 MPa pressure, a leaking pilot valve caused a depressurization of the main safety relief valve, which then opened. When the main valve opened a rupture disc, with design pressure of 3 MPa, broke causing an opening into the containment drywell. The resulting steam jet stripped fibrous insulation from adjacent pipework. Part of that insulation debris was transported to the suppression pool and subsequently clogged the intake strainers for the Containment Vessel Spray System about one hour into the event sequence. The so called ''strainer event" confirmed some of the concerns raised by nuclear safety specialists about a generic safety issue that had been identified about two decades earlier. This generic safety issue was concerned with the impact of dynamic effects of a primary pressure boundary breach such as a pipe break on the operability of emergency core cooling systems. While there had been a number of strainer ''precursor" events in the 1970s, 1980s and 1990s, it was the 1992 strainer event that prompted an extensive and still ongoing response by the international nuclear safety community.

The Swedish regulatory and industry response to the strainer event involved the establishment of R&D efforts that focused on physical phenomena associated with containment sump clogging issues, pipe break debris generation, debris transport and the technical basis for more realistic loss-of-coolant-accident (LOCA) frequency assessment. In part, the latter aspect of this broad R&D effort consisted of a 5-year R&D effort to explore the viability of establishing an international database on the operating experience with piping in commercial nuclear power plants. An underlying objective behind this 5-year program was to investigate the different options and possibilities for deriving pipe failure rate and rupture frequencies directly from service experience data as an alternative to probabilistic fracture mechanics (PFM). The R&D program culminated in an international piping reliability seminar in the fall of 1997 (Ref. 5) and the completion of a plant-specific LOCA frequency assessment pilot study in 1998 (Ref. 6).

A particularly important outcome of the aforementioned R&D program was the decision by SKI to transfer the pipe failure database including the lessons learned (Refs. 7 and 8) to an international cooperative effort under the auspices of the OECD Nuclear Energy Agency (NEA). Following on a series of information exchange and planning meetings organized by the NEA in 2000-2001, the "OECD Pipe Failure Data Exchange Project" (OPDE) was officially launched in May 2002 (Ref. 1).

I.B. OPDE/CODAP Project History

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

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

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

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

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

- Event-based failures that are attributed to damage mechanisms and local pipe stresses. Examples include high-cycle vibration fatigue due to failed pipe support, and hydraulic transient (e.g., steam or water hammer) acting on a weld flaw (e.g., slag inclusion).
- Failures caused by environmental degradation such as stress corrosion cracking due to combined effects of material properties, operating environment (e.g., corrosion potential, irradiation) and loading conditions.

The CODAP Event Database is a web based, relational (SQL) database consisting of ca. 100 data fields and about 800 database filters. A basic premise of the use of narrative information is to preserve the 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, dimensional data, etc. The event database structure, database field definitions and data input requirements are defined in a coding guideline, which is central to the project, including database maintenance, data validation and quality control. The database design has benefitted from a multidisciplinary approach involving chemistry, metallurgy, non-destructive examination, structural integrity and PSA. Each event record relates to a uniquely defined component boundary. The CODAP Event Database is restricted to participating organizations.

II. CODAP DATABASE STRUCTURE

As stated, the CODAP Event Database is a web based SQL database. 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. The “Online

Version" facilitates data input, search and query routines and data export to a local computer. On a local computer the database can be converted into a Microsoft® Access database format or any other user-defined format.

The CODAP event database is populated by the National Coordinators (NCs) of the member countries. In accordance with the Operating Procedures and QA Plan, validation of data submissions is performed by respective NC and the Operating Agent. To achieve the objectives established for the CODAP event database a coding format has been developed. This Coding Format is reflected in the Coding Guideline (CG). The Coding Guideline builds on established pipe failure data analysis practices and routines that acknowledge the unique aspects of passive component reliability in heavy water reactor and light water reactor operating environments (e.g., influences by material and water chemistry).

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 condition reports, 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 event tend to be documented to various levels of technical detail in these different information systems. Building a CODAP event database record containing the full event history often entails extracting information from multiple sources. The term "data quality" is an attribute of the processes that have been implemented to ensure that any given database record (including all of its constituent elements, or database fields) can be traced to the source information. The term also encompasses "fitness-for-use", that is, the database records should contain sufficient technical detail to support database applications.

As one-of-several-steps to ensure data integrity, all relevant source data are retained within the database. As one example, the narrative portions of the database retain all of the original event descriptions. Furthermore, a provision exists to attach supporting documents to each event record in support of independent validation of event classifications. 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. Each record in the database is assigned a CI, which relates to the completeness and comprehensiveness of the information in the database relative to the requirements of the Coding Guideline. The database structure consists of multiple data entry forms that are used to capture the fundamental piping reliability attributes and environmental influence factors contributing to a single pipe failure event. The data entry forms are organized to capture essential passive component failure information together with supporting information:

1. General Failure Data. This area represents the minimum required information and it includes an event narrative together with details on the affected component (e.g. diameter and wall thickness) and system, impact on plant operation, observed through-wall leak rate, and Code Class.
2. Flaw Size Information. This area is for recording flaw size (depth, length, and aspect ratio), orientation, location of the flaw (e.g. within weld metal, weld heat affected zone or base metal), and number of flaws within a specified component boundary. For record on multiple flaws within a specified component boundary, the distance between respective flaw is indicated.
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.
4. Root Cause Information. This area records factors or conditions contributing to a degraded condition or failure (e.g. through-wall leak, rupture). Also included in this area is a field for free-format comments on corrective actions, or other information of relevance to a specific event. The method and technique of flaw detection is recorded in this area of the database.

III. CODAP's CONTRIBUTION TO PLANT AGING MANAGEMENT

Introduced more than two decades ago, the concept of "aging PSA" (APSA) or "time-dependent PSA" was created to explore the analytical bases for assessing the effect of temporal changes in PSA input parameters on risk metrics; e.g. core damage frequency (CDF), large early release frequency (LERF). Short-term "aging effects" (e.g. equipment wear-out) tend to be highly predictable and, hence, pose a less challenging analysis problem than long-term aging effects for which there is limited service experience data available to support statistical analysis for trends. An aging effect can be defined as:

- Age-dependent change in a passive system, structure, or component (SSC) performance caused by an active degradation mechanisms or synergistic effects of multiple degradation mechanisms. Examples of changes in performance include:

  - Change in structural integrity of a piping or non-piping passive component. This change may be characterized by the estimated aging factor (AF), which can be calculated as the ratio of a projected hazard rate to the present-day hazard rate. This could be the hazard rate at end of current operating license or at some time increment from the current state-of-knowledge
  - Change in success criteria or functionality. Such a change can occur due to degraded heat transfer capability of a heat exchanger due to fouling or plugging of heat exchanger tuber. Similarly, a worn pump impeller would affect the shape of a pump curve and hence the flow capacity.
- Change in physical or chemical properties resulting from one or more active degradation mechanisms.

The prospects for developing APSA models hinge on the presence of a clear understanding of what constitutes an aging effect as opposed to readily identifiable, well understood temporal changes in equipment performance and human performance (via non-destructive examination). Access to high quality data that reflect several decades of plant operation is an important element of APSA. As opposed to standard PSA, an APSA model would explicitly account for the contributions to CDF and LERF by certain degradation mechanism. Furthermore, the effectiveness of aging management programs must be evaluated. Equally important is the feasibility of modeling a defined set of aging effects associated with the certain SSCs.

The physical degradation of metallic passive reactor components involves a complex interaction of material properties (e.g. chemical compositions, fracture toughness), operating environment (e.g. local flow conditions, pressure, temperature, water chemistry, and loading conditions. The effects of a certain degradation mechanism can be mitigated or eliminated through the applications of proactive aging management, including in-service inspection, stress improvement, chemical treatment of process medium. The CODAP database structure is a reflection of the physics of material degradation, and the database captures the subtleties of the many factors that contribute to material degradation and failure. Therefore, by utilizing the tools and techniques for querying the event records that are included in CODAP a basis exists for in-depth evaluation of temporal changes in the failure data, including positive and negative trends in passive component performance.

IV. CODAP's CONTRIBUTION TO PSA

At its June 2004 National Coordinators Meeting, the PRG decided to hold a Workshop on database applications. At the time the OPDE pipe failure database was foreseen to be user-oriented and application-oriented. The PRG had actively worked on these two items while designing the database and defining its technical content. Prior to the end of the first project phase in 2005, it was considered that National Coordinators and their organizations could give valuable inputs to this work by reporting on actual or planned applications.

Held in December 2004 and hosted by the Korea Institute of Nuclear Safety (KINS) and Korea Atomic Energy Research Institute (KAERI), the objective of the Workshop (Ref. 9) was to discuss applications of the OPDE database. By answering two basic questions that structured the Workshop, valuable insights helped improving the database structure and educated participants:

- How has OPDE been used?
- What can OPDE be used for?

From the outset, the OPDE/CODAP PRG membership has consisted of a multi-disciplinary group, including material scientist, structural integrity engineers, nuclear safety specialists and PSA practitioners. As anticipated, the 2004 Workshop produced a very broad list of potential applications, including:

<u>Applications related to the analysis of material degradation</u>
- Trend analyses of material degradation processes
- Identification of new degradation mechanisms
- Assessment of the effectiveness of degradation mitigation measures
- Assessment of the effectiveness of in-service inspection (ISI) programs; i.e. flaws not detected by prior inspection

<u>Applications related to PSA</u>
- Internal flood risk assessment
- High-energy line break analysis
- LOCA frequency assessment

- Significance determination process (SDP) assessment
- Accident precursor assessment

After a protracted inception process lasting several years, a first major application of the database was initiated in 2007 (Ref. 10) with the objective to produce a "handbook of pipe failure rates and rupture frequencies" ("R-Book") and to make it available to PSA practitioners. Sponsored by SSM and the Nordic PSA Group (NPSAG), the final product was issued in 2010 (Ref. 11). The 1st Edition of the proprietary Handbook consisted of a password protected CD with input/output files, a summary report, theory manual, and system-specific degradation mechanism analyses and relevant operating experience data summaries; total disc size is ca. 75 Mb. A series of 2010-2012 pilot studies were performed to demonstrate how to utilize the Handbook in plant-specific PSA applications (Ref. 12). Noteworthy is the fact is that data input to this effort was a non-proprietary version of the OPDE database as of 2007.

V. CODAP PSA APPLICATION INSIGHTS

The ability of an event database to support practical applications is closely linked to its completeness and comprehensiveness. Equally important is the knowledge and experience of the analyst in interpreting and applying a database given typical project constraints. Achievement of database "completeness" and "comprehensiveness" is driven by an in-depth understanding of application requirements. The presence of sustained institutional functions that promote the sharing of operating experience data is critical to the database completeness and comprehensiveness.

There are three general types of CODAP database applications: 1) high-level, 2) risk-informed, and 3) advanced applications. Extensive experience now exists with PSA-oriented database applications such as:

- Loss-of-coolant-accident (LOCA) initiating event frequency estimation.
- Internal flooding PSA; e.g., derivation of internal flooding initiating event frequencies.
- High Energy Line Break (HELB) Analysis. Consideration of HELB in PSA includes estimation of Main Steam and Feedwater line break (MSLB and FWLB, respectively) initiating event frequency. HELB is also a consideration in internal flooding PSA to address potential scenarios involving FWLB and water entering into the Auxiliary Building.
- Significance Determination Process (SDP) evaluation (also referred to as "accident precursor analysis") to determine the risk significance of an observed pipe degradation or failure.
- Risk-informed in-service inspection (RI-ISI) (Ref. 14).

This experience has been synthesized into a set of guidelines for how to structure and perform a well-qualified piping reliability analysis (Ref. 13). The guidelines identify pipe failure event database infrastructure considerations and the requirements on database integrity, nomenclature, damage and degradation knowledgebase, and high-level and supporting requirements for piping reliability analysis.

Data specialization is an intrinsic aspect of all PSA oriented applications. This encompasses several specific analysis tasks such as review and assessment of applicability of industry-wide service experience data to a plant-specific piping design (e.g., material, dimension, and operating environment), development of apriori failure rate distribution parameters reflective of unique sets of piping reliability attributes and influence factors, and Bayesian update of apriori distributions. The update may encompass consideration of different degradation mechanism (DM) mitigation strategies.

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) aging 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.

Based on the experience of the authors of this paper, the inherent latency in structured data collection efforts is on the order of five (5) years. This means that ca. 5 years could elapse before achievement of high confidence in data completeness. In other words, around 2020 the data mining for the previous decade (2006-2015) 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 programs 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 of 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. The CODAP Project has established such an infrastructure.

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 recognized 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 key to performing a well-qualified piping reliability analysis.

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.

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, aging management, and/or water chemistry programs?

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" should be an integral part of all qualitative analysis steps. It entails the identification of unique event subpopulations, time trends and dependencies. The U.S. service experience data with flow-accelerated corrosion (FAC) is used as an example to demonstrate the importance of data exploration and its impact on subsequent qualitative and quantitative analysis steps.

Under an assumption of no FAC mitigation and according the very extensive FAC knowledge base, there is a fundamental difference in the susceptibility of carbon steel to FAC in a BWR operating environment versus a PWR operating environment. Environment factors such as temperature, pH, amount of dissolved oxygen, and water impurities and additives affect the rate of material wear. For these and other reasons, the predicted wear rate tends to be greater in certain PWR piping systems than in corresponding BWR piping (Ref 14). Hence, driven by the knowledge base, in a first evaluation step the

BWR service experience should be separated from the PWR service experience. Next respective event population is further subdivided to address temporal changes failure rates that are attributed to the evolution of nondestructive examination (NDE) technologies as well as in NDE program implementation and NDE qualification.

The NDE programs to monitor FAC have evolved significantly. Current NDE requirements are more stringent and systematic than was the case prior to 1988 (Ref. 14). As one example, in 1987 the U.S. Nuclear Regulatory Commission issued Bulletin 87-01. The response to this Bulletin combined with industry initiatives to implement formal FAC-centered NDE programs resulted in new approaches to FAC management post-1987. These and other insights about FAC could be utilized to explore the impact of NDE on FAC-induced pipe failures over time. Figure 1 shows the cumulative number of pipe failures versus time to detect pipe wall thickness $t < t_{Min}$, where t_{Min} is the minimum calculated wall thickness allowed for continued operation. Four event populations are displayed in Figure 1; for each of BWR and PWR, an event population prior to 1988 and post-1987, respectively. In other words, for the PWR case the initial data exploration has established a prior (as in before implementation of systematic NDE) and posterior (as in after implementation of systematic NDE) event population. It is but one of many examples of how to qualitatively explore a database to establish an analysis strategy.

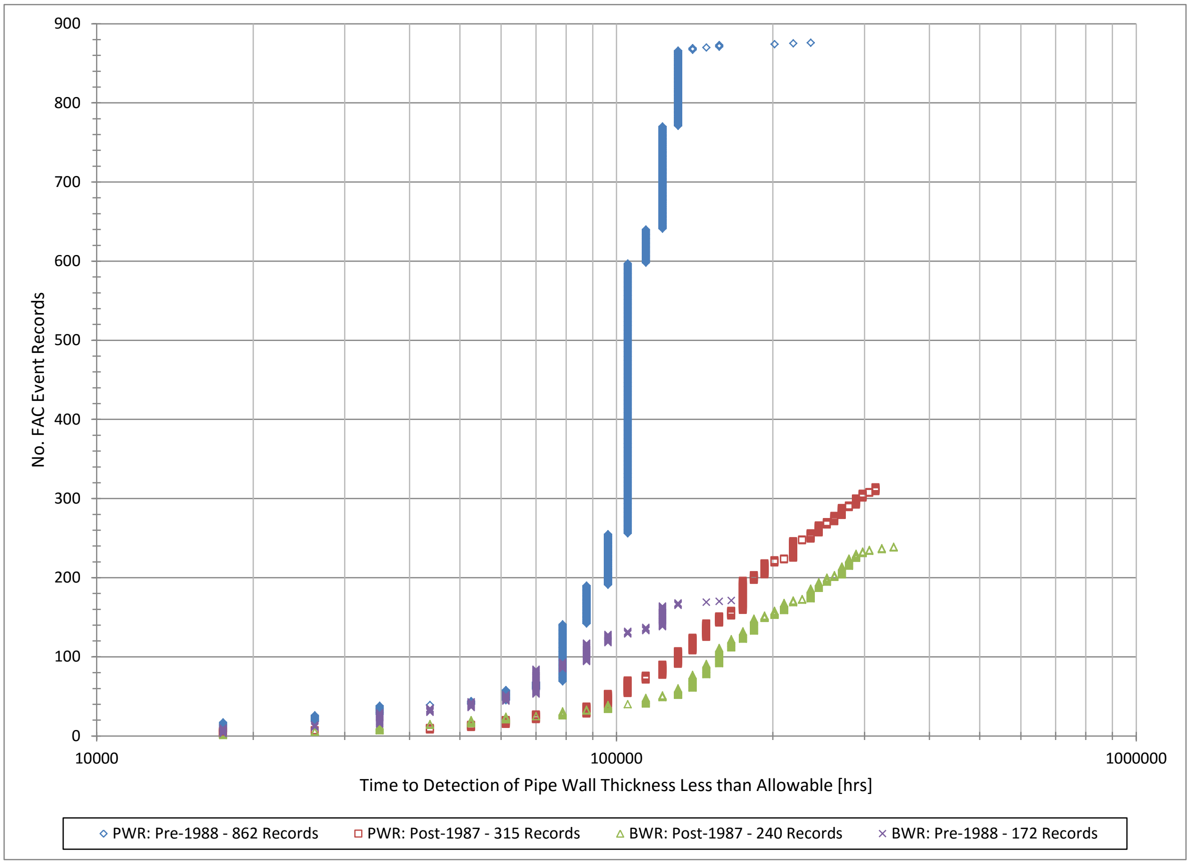

Fig. 1. Evaluation of U.S. Flow Accelerated Corrosion (FAC) Pipe Failure Data

A typical application tends to be computationally intense. In order to derive input to PSA model, several calculation cases must be defined to cover the appropriate range of degradation mechanisms and consequences of a pipe failure. A calculation case is defined by a unique set of pipe rupture frequency versus consequence of a certain, well defined magnitude usually characterized by either the size of a pressure boundary breach and/or through-wall flow rate. In support of a HELB analysis a total of 24 calculation cases were defined. A failure rate and rupture frequency distribution had to be developed for each case, and, hence a total of 48 parameter distributions were generated. As another example, in developing a location-specific LOCA frequency model for a pressurized water reactor (PWR) (Ref. 15) a total of 45 unique analysis cases were defined and a total of 462 parameter distributions were generated.

A carefully crafted analysis tool is needed to manage the calculation of piping reliability parameter distributions. The case studies referenced in this paper are based on an open Microsoft® Excel spreadsheet format with suitable add-in programs for uncertainty propagation and Bayesian update operations (Ref. 16). With the advancements in analysis methods and techniques follow new challenges in how to review and validate parameter distributions and the propagation of uncertainties. The entire process, from definition of calculation cases, definition of pipe failure database queries, definition of prior distributions, and performing calculations must be traceable and transparent to ensure efficient review processes.

VI. CONCLUSIONS

Since May 2002, the OECD/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 "OECD/NEA Component Operational Experience, Degradation and Aging Program" (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, eleven (11) OECD/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 insights reports available to material scientists as well as risk management practitioners. Data exchange among participating organizations enables comparisons of the different national practices regarding reliability and integrity management of passive components.

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). 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 OECD/NEA Data Project Operating Experience Data for Probabilistic Risk Assessment." Additionally, a proposal has been made for an international benchmark exercise concerning the use of service experience data to quantify piping reliability parameters for input to a standard problem application; e.g. risk informed operability determination.

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