

**Karen GOTT, SKI (Sweden)****The regulatory position in sweden concerning ageing management as of early 2005**

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**ABSTRACT**

Until the late 1990's the political situation in Sweden was such that long-term ageing management was not a regulatory concern. All Swedish nuclear power plants were to be shut down by 2010. In the most recent SKI (Swedish Nuclear Power Inspectorate) regulations which came into effect 2005-01-01 the utilities are required to submit an ageing management programme to SKI by 2005-12-31. Currently SKI is drawing up guidelines in preparation for the assessment of these programmes. One of the aspects which will be considered in forming the guidelines is the approach taken in other countries. Another of the central considerations will be the potential degradation mechanisms for different systems and components in Swedish plants.

The nuclear power plants in Sweden are required to report all cracks to SKI. This rule applies to all the systems covered by SKI's regulations concerning the structural integrity of mechanical components. As a result SKI has over the years gathered extensive information concerning the history of the various degradation mechanisms which have been observed in Swedish plants. This information has been put into a database set up specifically for the purpose, known as STRYK. The information in the base includes details of when and how the cracks were detected, their dimensions and cause, as well as system and component details. The database also has a comprehensive reference list of all the related documentation associated with a crack or group of cracks. STRYK will be described and its use and limitations illustrated.

STRYK will provide a central tool in evaluating potential degradation mechanisms to be considered in the aging management programmes. With regard to the Swedish BWR fleet it is comprehensive. However, the data on the secondary side of the PWR plants are not truly representative of their degradation history because of the reporting practices in Sweden. Another important source of information for degradation in plants is OPDE, the international piping failure database established by OECD-NEA.

## THE LEGAL BASIS FOR SWEDISH REGULATION

The nuclear power programme in Sweden comprises twelve reactors: nine Boiling Water Reactors (BWR) designed and built by ASEA ATOM AB (later ABB Atom AB, and now Westinghouse Electric AB) and three Westinghouse designed Pressurized Water Reactors (PWR). There are four separate sites all situated on the coast, two on the west coast and two on the east with between two and four reactors per site. The first reactor was commissioned in 1972 and the most recent in 1985. Two BWR reactors have been closed for political reasons.

The legal basis for the regulatory activities in Sweden is to be found in a number of different types of documents: laws, governmental ordinances, annual government letters of appropriation and specific government decision, including licensing decisions. Through government ordinances and specific decisions the Swedish government delegates specified parts of the legal authority to the Swedish Nuclear Power Inspectorate (SKI) and the Swedish Institute for Radiation Protection (SSI). The key legal documents pertaining to nuclear safety are the Act on Nuclear Activities and the Ordinance on Nuclear Activities. The general tasks for SKI and SSI are specified in separate Ordinances (instructions) and more recently in the annual letters of appropriation. Radiation protection is regulated in a separate law, the Radiation Protection Act.

The main law which regulates nuclear safety in Sweden is the Act on Nuclear Activities (1984:3) which came into force in 1984 and was later amended in 1992 and 1994. This law contains basic provisions on safety in connection with nuclear activities for the operation of all nuclear installations as well as the handling of all nuclear materials and nuclear waste. Nuclear activities are to be conducted in such a way as to meet the safety requirements and fulfil the obligations pursuant to Sweden's agreements to prevent the proliferation of nuclear weapons and the unauthorized dealing in nuclear material and nuclear waste in the form of spent nuclear fuel. The safety of nuclear activities is to be maintained by taking those measures required to:

- Prevent errors in, or defective functioning of, equipment, incorrect handling or anything else that might result in a radiological accident;
- Prevent unlawful dealings with nuclear materials or nuclear waste.

A license is required for all nuclear activities granted either by the Swedish Government or the authority appointed by the Government. The license may be revoked by the authority appointed by the Government if the stipulated conditions have not been complied with in an essential way; there are specific safety issues, severe misconduct on the part of the licensee, or they have not fulfilled their obligations concerning research and development efforts. In 1997 the Law was amended to permit the Government to close a nuclear power plant for the purposes of energy system conversion.

The holder of a license for nuclear activities has to ensure that all necessary measures are taken to maintain the safety of the plant. This is a very general obligation and it is

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complemented with license conditions imposed when the license is issued, but additional conditions can also be imposed as long as the license is valid.

A licensee shall, if required by the regulatory body, submit all the information and documentation necessary to execute its supervision, provide access to the installation or site for investigations and controls necessary for the supervision. The regulatory body has the right to make all the necessary decisions concerning measures, conditions and prohibitions in individual cases to ensure the implementation of the Act on Nuclear Activities.

Sweden considers it essential that the public have insight and information concerning nuclear activities. Basic information is provided by the two regulatory authorities, SKI and SSI. In municipalities with major nuclear power facilities it is particularly important that the residents have easy access to qualified information and local liaison committees have been established to meet this need. The plant must provide the committee with information and relevant documentation. The committee is not supposed to impose requirements or to prescribe other measures for implementation by the plant, this right rests exclusively with the regulatory authorities.

The Ordinance on Nuclear Activities (1984:14) confirms SKI as the regulatory authority in accordance with the law and permits SKI to issue licensing conditions and general regulations on measures to maintain safety in matters concerning nuclear safety.

### **The safety case as the basis for licensing and nuclear supervision**

For the currently operated Swedish nuclear power plants the original license to build, own and operate each plant was granted by the Government based on an application early in the reactor design process. Consequently the licensing decision was based on a general technical description of the reactor. In each licensing decision the Government prescribed a number of conditions to be fulfilled, on the recommendation of the regulatory body (SKI's predecessor, the Commission on Atomic Energy). These license conditions required that a preliminary safety analysis report (PSAR) be submitted and approved by the regulatory authority before starting major construction activities. A final safety analysis report (FSAR) and the technical specifications for operation (STF) were to be submitted and approved prior to commencing nuclear operation. These documents were written following the general guidelines issued by the Swedish regulatory authority in which reference was made to the US NRC 01CFR50 documentation as it became available.

After approval the FSAR and STF became the legally binding documents regulating the technical configuration of each reactor and its operating limits and conditions, often referred to as "the safety case of the reactor". This can be regarded as defining the minimum safety level that a licensee is legally committed to maintain as a permit to operate the reactor. It also provides the basis for the regulatory supervision. Changes in this basic documentation require the approval of SKI on a case by case basis.

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Additional license conditions are prescribed by SKI based on national and international operating experience and new research insights but also based upon new international requirements. Such license conditions can be permanent or applicable for a limited time, for example stricter in-service inspection requirements pending the replacement of damaged components. They may also be specific to one reactor or apply to a group of reactors. Although there are a number of common features, the legal basis for the regulatory supervision of the nuclear power plants is in fact based on individual sets of regulatory documents, one set for each reactor.

### The development of general regulations

Through an amendment to the Act on Nuclear Activities SKI was granted the authority to issue general regulations from the beginning of 1993. The first regulations concerned the structural integrity of nuclear components, SKIFS 1994:1. The general safety regulations, SKIFS 1998:1 "Regulations concerning safety in certain nuclear facilities", first came into force on July 1<sup>st</sup> 1999. Both these regulations have been updated, SKIFS 2000:2 and SKIFS 2004:1 respectively. Based on operating experience, safety analysis, research and development and updated international standards SKI has also issued general regulations on design and construction that SKI believes are justified for the continued operation of Swedish nuclear power plants after 2010, SKIFS 2000:4:2.

In the latest version of the "Regulations concerning safety in nuclear facilities", SKIFS 2004:1 the requirement for an ageing management programme has been introduced in Sweden for the first time.

*"From Chapter 5 § 3: ..... Programmes for maintenance, surveillance testing and control as well as for the management of ageing degradation shall exist. The programmes shall be documented and shall be reviewed and updated in the light of experience gained as well as the development in science and technology. .... "*  
*With the accompanying general recommendations: ".....The programme for the management of ageing degradation and damage should comprise the identification, monitoring, handling and documentation of all the ageing mechanisms that can affect structures, systems and components as well as other devices that are important for safety. .... "*

Programmes for ageing management had not previously been deemed necessary since all nuclear power plants were to be shut down by 2010, but the situation today is very different with utility plans for power uprates and extended life. All nuclear installations must submit their programmes to SKI by the end of 2005 and preparations are under way to perform the appropriate assessments thereafter.

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## STRYK – A DATABASE OF STRUCTURAL COMPONENT DEGRADATION

According to the regulations governing the structural integrity of mechanical components any degradation must be reported to SKI as any other deviation from the legal operating basis. The exact wording of this requirement has varied over the years but has been in effect in one form or another since early in the Swedish nuclear programme. The plant may not restart after a shutdown if there remain serious doubts as to the cause of such degradation, since the calculations of the remaining life or mitigating actions necessary depend upon the specific degradation mechanism. It is normal practice in Sweden that damaged components be replaced, if not immediately as soon as practical in a planned manner. In many cases the removed components have been examined in considerable detail, and the results reported to SKI. In recent years there has been an increased tendency to use such components in the inspection qualification programmes and for training purposes. Thus over the years considerable information has been submitted, and SKI has used this to establish a database of all the cracks and other forms of degradation that have occurred in the mechanical components in Swedish nuclear power plants during their operational lives.

The real work on this database was started in 1993 when the information was systematised and recorded in an agreed form. The results of this inventory were then sent to the utilities for control both of the entries themselves, and also to ensure that no defects had been omitted. This control phase took nearly two years, and the results varied in quality from site to site. The intention has always been to have as complete a database as possible and not only to include the major systems and components but everything that is covered by the regulations. Since this initial stage the database has been populated on a regular basis and errors corrected and new entries added as information has been found in the various archives that a 30 year old organisation has.

The electronic database is known as “STRYK”. In association with the electronic records there is a system of files in which all the background references are stored, and which is part of the official archives of SKI and includes cross references to the electronic database and other official records. The main menu, see Figure 1a, comprises a number of pull down menus, and also enables access to free text fields for more detailed information such as root cause analysis, and references. An advanced search motor can be used directly in STRYK or the electronic extracts from the database which are automatically generated regularly can be used in the applications EXCEL and/or ACCESS.

Analysis of the information in STRYK can be carried out on several different levels. Comparisons can be made between the different plants or between different systems in the same plant. As with analysis of any database considerable care must be exercised when comparisons are made, and conclusions should be limited to areas in which there is sufficient information that results are not questionable. The knowledge that there are deficiencies in the database have led SKI to be very restrictive in the release of STRYK for general use, both

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internally and within the nuclear community within Sweden and abroad. The reporting systems which exist in Sweden have resulted in a comprehensive database, but one which is biased in a number of respects. One example of this is the reporting of erosion-corrosion degradation in auxiliary systems where the reporting rules have varied over the years, and have also been interpreted differently by the plants and representatives of the third party control organisation. The quality of the information for components in classes 1 and 2 is considered to be high. The materials experts at the plants have made considerable efforts to ensure both that all cracks and other degradation reports have been made available, and that the content of these reports is sufficient for adequate information to be included in STRYK.

The screenshot displays the STRYK 2000 1.3.3 software interface. The main window is titled 'Skador' (Damage) and contains various input fields for recording degradation events. The interface is organized into several sections:

- Top Bar:** Includes menu options like 'Arkiv', 'Redigera', 'Funktioner', 'Utskrifter', 'Systemhantering', and 'Om'.
- Buttons:** 'Ny' (New), 'Ändra' (Edit), and 'Bort' (Delete) are located at the top left.
- Input Fields:**
  - Löpnummer:** 00103
  - Diarienummer:** 7.23/900620
  - Anläggning:** F2
  - Systemnummer:** 331
  - Arkiv:** F2/1 Flick 4.
  - Komponenttyp:** T-stycke
  - Komponent Id:** E005
  - Kvalitetsklassning:** 2
  - Kontrollgrupp:** B
  - Skadeti:** 85
  - Skadeklass:** (empty)
  - Tidpunkt:** 9005
  - Drifttid:** 8.8
  - Upptäcktsätt:** Ultraljud (UT)
  - Driftläge vid upptäckt:** Revision
  - Placering:** Grundmaterial
- Typ av skada:** Spricka, konstaterat
- Orientering:** Axiell
- Skademekanism:** Termisk utmattnings
- Åtgärd:** Utbytt
- Material:** SS SA 376-304
- Dimensions:** Längd: 24, Djup: 9.5, Komponentdiameter: 168, Tjocklek: 12.5
- Material Properties:** Δ T °C: 55, C-halt %: (empty)
- Checkboxes:** Skadeorsak, Skadeanalys, Skadetålighetsanalys, Övrigt, Materialanalys, Referenser, Miljö, Se även.
- Metadata:** Skapad: 1996-07-10, Uppdaterad: 2000-06-20 12:37:00, Av: MONA
- Buttons:** 'Spara' (Save), 'Avbryt' (Cancel), and 'Stäng' (Close).

The bottom of the window shows a Windows taskbar with the date 2000-09-12 and time 14:02.

Figure 1: The main menu in STRYK

To date there are more than 1800 entries in STRYK covering more than 1350 different events. An event is defined as all degradation in a given component at a given time (i.e. information can be available for many separate cracks in one and the same event). It is possible that information from several different inspections exists for a given event, and these are included in STRYK in order to aid the studies of the development of degradation, and to enable comparisons between laboratory and field data. If information is available concerning more than one separate crack or area of degradation in a specific component at a specific time, this is entered as a separate data post in order to enable analysis of for example

inspection efficiency. The following examples will concentrate on damaged components rather than separate cracks.

### Examples of trend analyses made using STRYK

One of the most obvious plots which can be made is the number of events as a function of time. This can either be calendar time, as shown in Figure 2a, or operational time, as shown in Figure 2b.

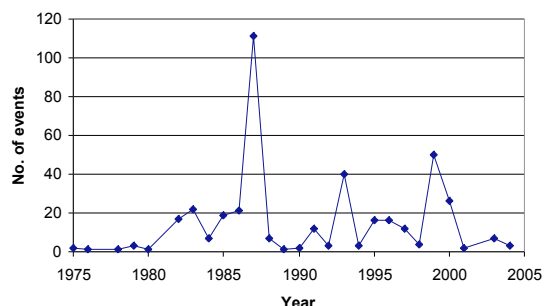


Figure 2a: Number of events per calendar year

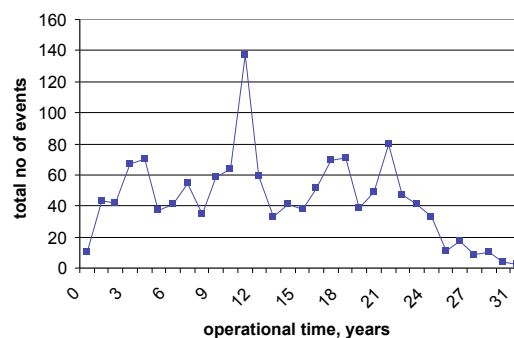


Figure 2b: Number of events per operational year

The difference in the shape of these two plots is in part explained by the varying age of the plants. The highest number of events in 1987 after 18 years operation coincides with the replacement of a large quantity of piping in the oldest two BWRs because of stress corrosion cracking. Most of the cracks were in fact found after pipe removal in an extensive inspection and metallographic study. In 1999 there is another peak due to stress corrosion cracking, this time in vessel internals in the older BWRs. These cracks were first observed in 1999 because of improvements in the inspection techniques, but they had formed much earlier. In the STRYK database it is the date of detection which is entered since it is not possible to extrapolate back in time to the date of crack initiation. No information about initiation times can be obtained from the database. However by adding information from further inspection after detection supporting evidence for degradation rates in the plants rather than the laboratory can be obtained.

The detection methods are illustrated in Figure 3. From this it is evident that over 90 % of the cracks and other forms of degradation have been captured in the in-serve inspection programmes. This in turn means that a very small proportion of the cracks are through wall, less than 10 %.

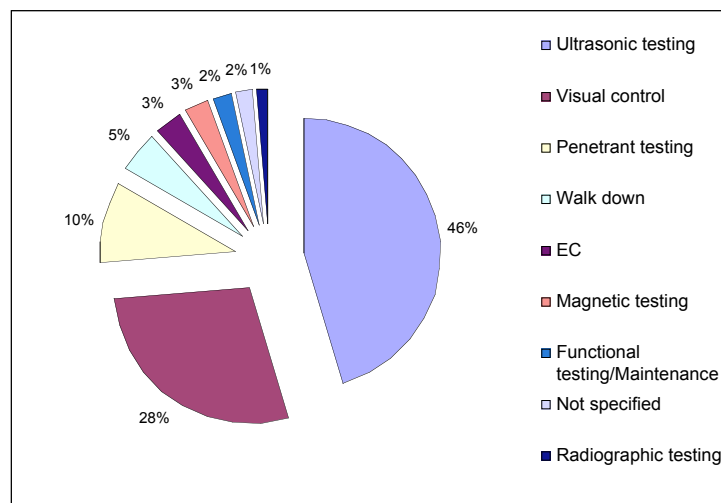


Figure 3: Detection methods

It is also possible to see which degradation dominate in the Swedish plants, as shown in Figure 4. This figure illustrates indirectly that a root cause analysis has been performed for most of the events. In many cases boat samples have been taken and examined metallographically. In other cases the damaged component itself has been examined after being replaced.

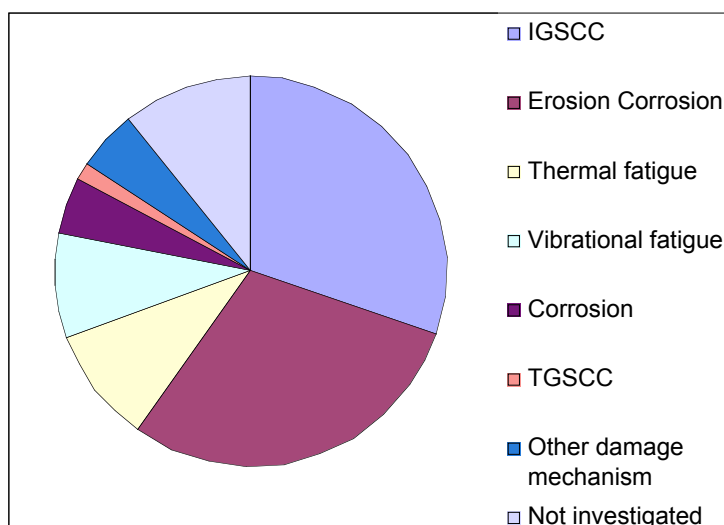


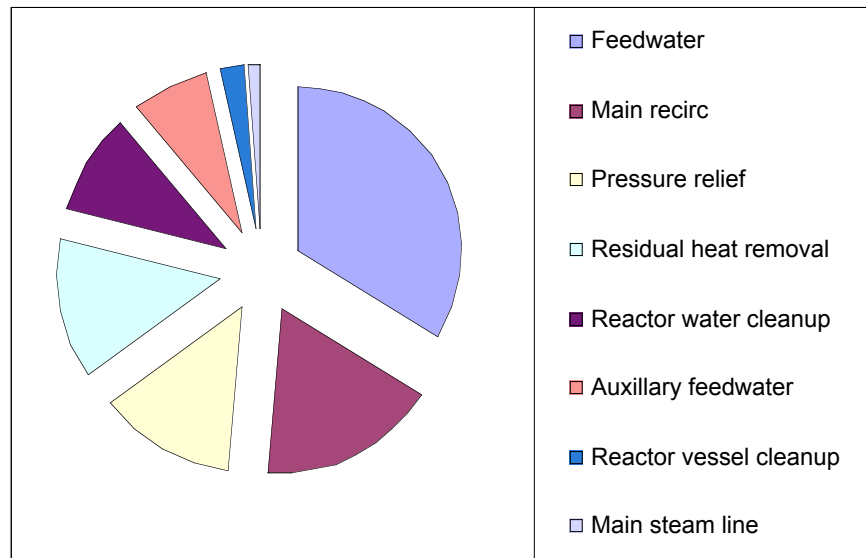
Figure 4: Most dominant degradation mechanisms in Swedish plants

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The systems which have had the largest numbers of cracks or other forms of degradation are shown in Figure 5.



*Figure 5: Most affected systems in Swedish plants*

There are a number of interesting differences between the Swedish plants as illustrated in Figures 6 and 7. The frequency of erosion-corrosion varies considerably despite the fact that there have been programmes in place since the plants were first taken into operation. Erosion-corrosion also illustrates the differences in reporting policies from the various sites. The three PWR units (Ringhals 2 – 4) have apparently a very low frequency of such damage. This is at least in part due to their interpretation of the reporting requirements over the years. The high frequency of the events in Forsmark 1 and 2 are the result of wet steam and this has recently been remedied by replacing the steam separators. In Barsebäck 1 and 2 the introduction of hydrogen water chemistry to mitigate stress corrosion cracking led to increased erosion-corrosion. This was remedied by dosing oxygen to the affected systems.

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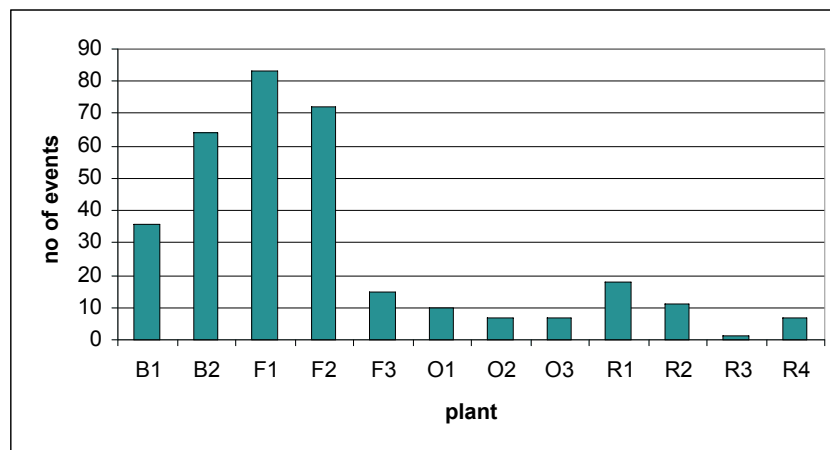


Figure 6: Incidences of erosion-corrosion in Swedish plants

Another interesting observation is that two basically identical plants, Forsmark 3 and Oskarshamn 3 have very different statistics concerning vibration fatigue, as can be seen in Figure 7. No explanation has been found for this.

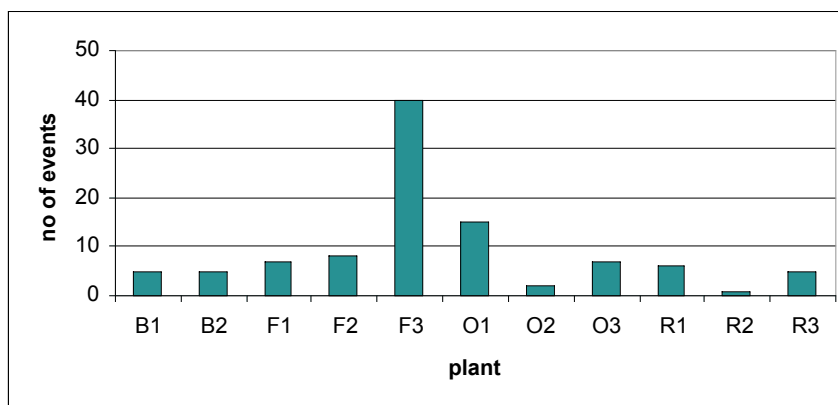


Figure 7: Incidences of vibration fatigue in Swedish plants

## CONCLUDING REMARKS

The importance of gathering information concerning component degradation has been accentuated by the needs of ageing management as well as the increased interest in probabilistic safety analyses studies of plants. This has been recognised at the international level through OECD Nuclear Energy Agency's Committee on the Safety of Nuclear Installations (CSNI). There is an on-going international effort involving twelve countries known as the OECD Piping Failure Data Exchange Project (OPDE). However, in order to follow the development of degradation mechanisms and correlate them to ageing, maintenance and inspection programmes it is necessary to encompass all the relevant systems

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and components and not to limit information to piping. Sweden will continue to participate actively in the OPDE project, and try to ensure that the information made available is of good quality and sufficiently comprehensive to be of use in these and other applications.

The Swedish database, STRYK, demonstrates that the most frequently occurring mechanisms are similar to those in other countries, but that erosion-corrosion and thermal fatigue have a more prominent place when all systems and components are considered than when only piping is considered. Both these degradation mechanisms continue to be found in the Swedish plants. The causes of IGSCC are dominated by cold work and not sensitisation which is the area of this phenomenon that has been studied in more detail. There is also an increasing problem with nickel base alloys, and in recent years more cases of IGSCC have been found in the PWR plants. The Swedish plants do not in general have components which would as yet be expected to be subject to irradiation assisted stress corrosion cracking, and confirmatory inspections have been made of components such as the core shrouds and baffle bolts.

One of the important conclusions which analysis of STRYK emphasises is that in-service inspection programmes must continue both to monitor the degradation of components for which mitigation measures are inadequate, and also to ensure that unexpected events are caught before component failure. One of the recurring problems in this respect has been the incidence of cracking associated to weld repairs which are often more extensive than documented or not documented at all. To date the Swedish programmes have been successful in this respect and the development of more detailed risk informed inspection programmes ought to ensure that efforts are directed appropriately.

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