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Swiss Federal Nuclear Safety Inspectorate's Guideline for Ageing Surveillance of Mechanical and Electrical Equipment and Civil Structures in Nuclear Installations

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Abstract

In Switzerland four nuclear power plants (NPPs) with five reactors are in commercial operation. Additionally there are a few research facilities as well as installations for treatment and interim storage of radioactive waste. The oldest NPP reactor Beznau 1 is in operation since 1969, Beznau 2 since 1971, and Mühleberg since 1972. All NPPs have accumulated well above 150'000 hours, some even over 250'000 hours on the grid. For that reason ageing surveillance is of major importance to the Swiss nuclear regulator.

HSK has required, since 1991, that for each NPP there is a comprehensive ageing surveillance programme (ASP) in place. It covers the aspects of material degradation in the areas of mechanical and electrical systems and components as well as civil structures. HSK has recently issued a guideline "Ageing Surveillance of Mechanical and Electrical Equipment and Civil Structures in Nuclear Installations" (HSK-R-51/d, November 2004) that addresses the basic requirements of ageing surveillance and organizes the regulatory aspects of the ageing surveillance programmes and the corresponding documents. This guideline is mainly written for the operating commercial nuclear power plants but shall also be applied for other nuclear installations with modified requirements.

One of the main tasks of ageing surveillance is to identify ageing mechanisms that have the potential to cause damage in structures, systems, and components and thus to influence the safe operation of the plant or installation. The existing measures to determine the state of a structure or a component (e. g. in-service inspection programmes, maintenance, monitoring and testing) have to be evaluated with respect to their effectiveness to detect ageing mechanisms that act on the component. It has to be determined if additional measures have to be set up in order to detect and monitor ageing or even to counteract ageing degradation.

Pressure retaining components of the primary coolant system have to be treated in full extent, as well as the primary containment and the essential parts of the safety systems, where the selection is supported by the results of probabilistic safety assessment (PSA). The information on possible ageing mechanisms on all potentially affected positions in a system has to be used to complete in-service inspection, maintenance and testing programmes and to choose NDT testing positions. The Swiss regulation on in-service inspections of mechanical components NE-14 requires the qualification of NDT systems. Test blocks in qualification procedures shall contain representative defects that are designed on the basis of ASP information.

Chemistry control of the reactor water and transient book keeping are other key issues in the ASPs of the primary coolant system and last but not least an effective leakage monitoring system to prevent an external attack to the pressure boundaries. These programmes are well established in the Swiss nuclear installations.

Introduction

In Switzerland nearly 40% of electric power is produced by nuclear power plants (NPPs). The characteristics of the Swiss NPPs are given in Table 1. The question of ageing of systems, structures and components (SSCs) in Swiss NPPs was already addressed by HSK in 1991, after some unexpected damage due to material degradation had occurred. This raised the question whether ageing phenomena could seriously challenge the safe operation of NPPs even before the end of design life had been reached. Furthermore, the question arose if it would be possible to continue safe operation after the nominal design life of the plant. For this reason, HSK has required, since 1991, that for each NPP there is a comprehensive ageing surveillance programme (ASP) in place. In response to this HSK requirement, the Group of Swiss Nuclear Power Plant Operators (GSKL) established a Swiss utility working group for ageing management, and worked out a basic programme and guidelines for the ASPs [2]. The basic programme from GSKL, approved by HSK, describes the principal steps of an ASP.

Table 1: Characteristics of Swiss Pressurised Water (PWR) and Boiling Water (BWR) NPPs. Status at the end of 2004.

Name	Type	Manufacturer	Net Capacity (MWe)	Commercial Operation since	Accumulated operating hours
Beznau-1	PWR (2-Loop)	Westinghouse	365	1969	260267
Beznau-2	PWR (2-Loop)	Westinghouse	365	1971	255926
Mühleberg	BWR	General Electric	355	1972	255742
Gösgen	PWR (3-Loop)	Siemens KWU	970	1979	202029
Leibstadt	BWR-6	General Electric	1145	1984	156546

The new Federal Order to the Nuclear Energy Act that came into force in February 2005 requires ageing surveillance for nuclear installations. HSK has recently issued the guideline "Ageing Surveillance of Mechanical and Electrical Equipment and Civil Structures in Nuclear Installations" (HSK-R-51/d, November 2004) [1] that addresses the basic requirements of ageing surveillance and organizes the regulatory aspects of the ageing surveillance programmes and the corresponding documents. This guideline has to be applied to the Swiss NPPs which range among the first and second generation of NPPs (Fig. 1). The fulfilment of the requirements stated in the guideline is an important prerequisite for all NPPs to continue operation up to 50 or 60 years as it is envisioned by the Swiss NPP operators.

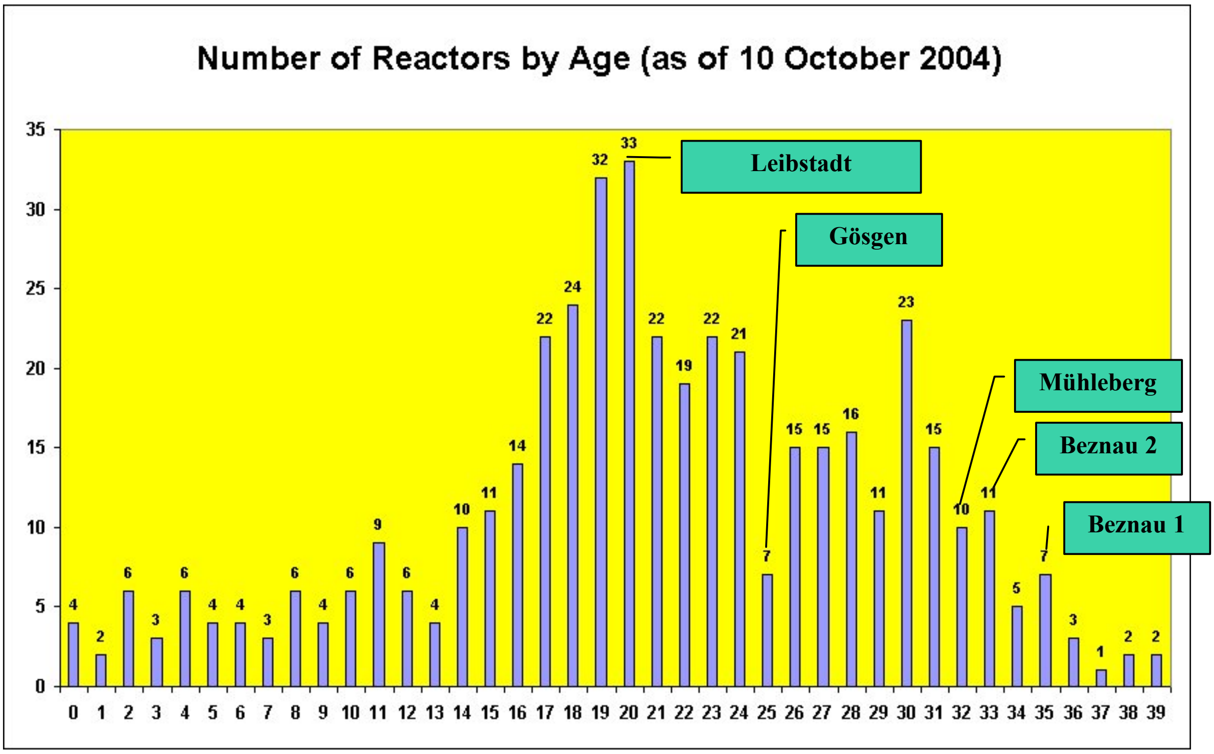

Figure 1: Number of reactors by age in years according to IAEA statistics.

Recent ageing issues in Swiss NPPs

Core shroud cracking is observed since 1990 in the NPP Mühleberg. Since 2000 the internals are treated with noble metal chemical addition (NobleChem^{TM}) and hydrogen water chemistry. So far no effect on the crack growth rate in the core shroud could be shown and the effect on crack initiation is not conclusive. The operator plans to use a modified way of application (On-line NobleChem^{TM}), which is expected to show a better effect on the crack growth of the existing cracks. The monitoring of core shroud cracking will be an open issue of ageing surveillance for HSK in the future.

Alloy 600 penetrations of reactor pressure vessels (RPV) are inspected in Swiss NPPs since about 1992 by volumetric NDT methods such as ET and UT. No cracks have been found until today. The reassessment of SCC susceptibility of reactor vessel head penetrations in the course of the ASP in NPP Beznau 1 and 2 now leads to an enhanced ISI programme that includes ET/UT examinations as well as bare vessel head visual inspections with inspection intervals of four years. Bottom head insulations in both blocks are modified to grant better accessibility of the bottom head penetrations.

Several steel containment structures show corrosion resulting from reactor pool or other temporary leakages. The corrosion appears mostly in inaccessible areas between concrete structures and the steel containment. The results obtained by special ASP inspections show that wall thickness still meets the design criteria in all NPPs. Future efforts in ageing surveillance are directed to monitor the state of corrosion and to reduce and stop the leakages or to mitigate corrosion by other means.

In 2003 cracks were found in the safe end and reducer of the RPV nozzle of the CRD return line of the NPP Mühleberg. The thermal sleeve which protects the nozzle showed heavy cracking but was still in place. The damage mechanism was identified as thermal fatigue (stratification) due to primary water of 40°C being injected though the nozzle during power operation. This mechanism was underestimated by the plant specific ASP because wrong values of flow were used in the calculation of the temperature distribution for the nozzle. The safe end and reducer were repaired by temporary overlay welding and the nozzle will be closed and capped in 2005. The system flow has been rerouted through the CRD-system since 2004.

Definitions and service life of NPP equipment

The HSK guideline [1] gives the following definitions in relation to ageing

- Ageing: Cumulative, time-dependent change in physical and/or chemical properties of nuclear equipment that has been caused by one or more ageing mechanisms.

- Ageing Surveillance: All time effective measures of timely recognition, evaluation and mitigation of the state of ageing of nuclear equipment.

- Ageing Surveillance Programme (ASP): Systematic procedure to check the influence of ageing on NPP installations, to evaluate the state of ageing and to check existing measures of ageing surveillance with respect to completeness and efficiency. It aims at the recognition of deficiencies in ageing surveillance and at measures to close these gaps.

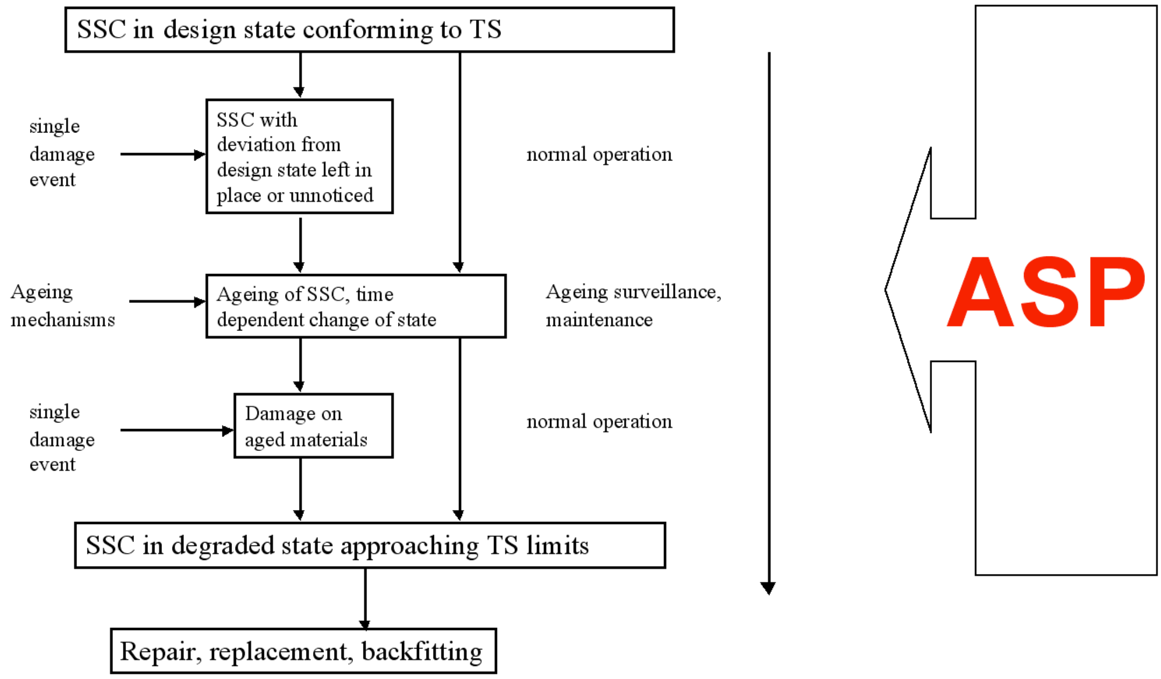

Figure 2: Service life of systems, structures, and components (SSC) from design state to the limits of Technical Specifications (TS).

Ageing surveillance has to take into account that ageing of equipment may be influenced by undiscovered flaws from fabrication, by single damaging events or by the interaction of several ageing mechanisms (Fig.2). The driving force of ageing may come from operating conditions and media as well as from the environment.

Thus the Swiss ageing surveillance guideline concentrates on the aspects of ageing of materials and devices and the consequences thereof. Other aspects of ageing may be technical obsolescence, ageing of documentation, or personnel ageing. These aspects are not within the scope of the guideline [1], but are treated in other areas of HSK activities, e. g. in the assessments of periodic safety reviews (PSR).

Requirements for ageing surveillance

HSK requires the ASP to cover the following tasks [1, 2]:

- Identification of ageing mechanisms based on the knowledge of ageing degradation from international experience in NPPs.
- Identification of those parts of the plant that are affected by ageing. The scope has to include all safety relevant systems, structures and components (SSCs), i. e. classified and in special cases, also unclassified SSCs, if necessary. HSK considers probabilistic risk assessments (PRA) / probabilistic safety assessment (PSA) applications to be a tool to identify components of special importance to safety.

- Inventory and check for completeness of the existing ageing surveillance (in-service inspection, testing and maintenance programmes).
- Evaluation of inspection methods and techniques with respect to effectiveness for the detection of ageing phenomena.
- List of further actions necessary for the surveillance and assessment of ageing phenomena.

The results have to be summarized in catalogues of ageing mechanisms and plant specific ASP documents on SSCs. ASPs are carried out in the field of civil engineering, electrical engineering and mechanical engineering. The NPPs have also to provide interface documents that describe the treatment of components which belong to more than one of these fields.

Civil engineering

The ageing surveillance of civil structures addresses the following materials:

- Concrete and Reinforced Concrete
- Iron and Steel, Reinforced Steel, Tensioning Steels
- Anchors
- Fire Bulkheads
- Joint Tapes, Seals
- Paints and Coatings

An inspection plan is set up for all important civil structures on the basis of a 10-year inspection interval. It starts with a basic or main inspection, continues with intermediate inspections after 5 years and if necessary with special inspections like examination and testing of concrete samples. The main types of inspections used in civil engineering are visual inspections.

Electrical engineering

The ageing surveillance of electric equipment address ageing mechanisms of about 30 types of both active and passive electrical components. The ASP has a strong relation to ongoing qualification programmes, where pre-aged samples of electrical components are tested for fitness to operate under normal and upset conditions. The ageing of cables is monitored by samples that are placed at locations with high radiation levels and high temperatures in the NPP. Regular testing of the samples reveals if the mechanical properties (e. g. elasticity) of the insulation of the cables still fulfil requirements.

Mechanical engineering

Ageing surveillance of mechanical equipment is strongly related to the maintenance programmes that are in place since the beginning of operation in all Swiss NPPs. A selection has to be made for ASP documentation in detail. The following mechanical equipment has to be included in the ASP documentation:

- all components of the pressure retaining boundary of the primary coolant system (safety class 1)
- Reactor pressure vessel internals (safety class 2 and 4)
- all components of the of the primary containment system (safety class 2)
- essential parts of safety systems that are required in the case of safety function demand (safety class 2 and 3)
- components of safety systems where the susceptibility to ageing damage has to be evaluated in order to fulfil the requirements of the regulation NE-14 [3]
- risk relevant components irrespective of safety class where the selection is based on results of probabilistic safety assessment (PSA)
- other components which are important for reasons like operation and radiation protection and which are selected by an expert panel of the NPP

Mechanical engineering mostly deals with metallic components. To a minor extent, elastomers and other materials are involved. Materials like seals and hydraulic oils, which are exchanged in regular intervals during preventive maintenance work, are supposed to be under sufficient ageing surveillance and are not addressed in detail. The GSKL-ageing catalogue lists a number of ageing mechanisms of several types of corrosion, fatigue, embrittlement and mechanical effects like erosion or deformation. In addition to those ageing mechanisms generally applicable to the materials present, and known on a global NPP experience basis, component-specific ageing mechanisms are also included. For example, a mechanism defined as "Loss of function", is applicable for active components which can fail due to the accumulation of deposits (e. g. crud, loose parts). International experience with cases of damage due to ageing is evaluated periodically by both HSK and the Swiss plant operators. The gathered generic knowledge has to be applied to the plant specific situation (Fig. 3). The ASP results have to be listed in a detailed ASP documentation where each position of a system or component which is susceptible to ageing can be identified. Supplementary actions are initiated in cases where ageing mechanisms are relevant, but no ISI or other suitable surveillance methods are in place.

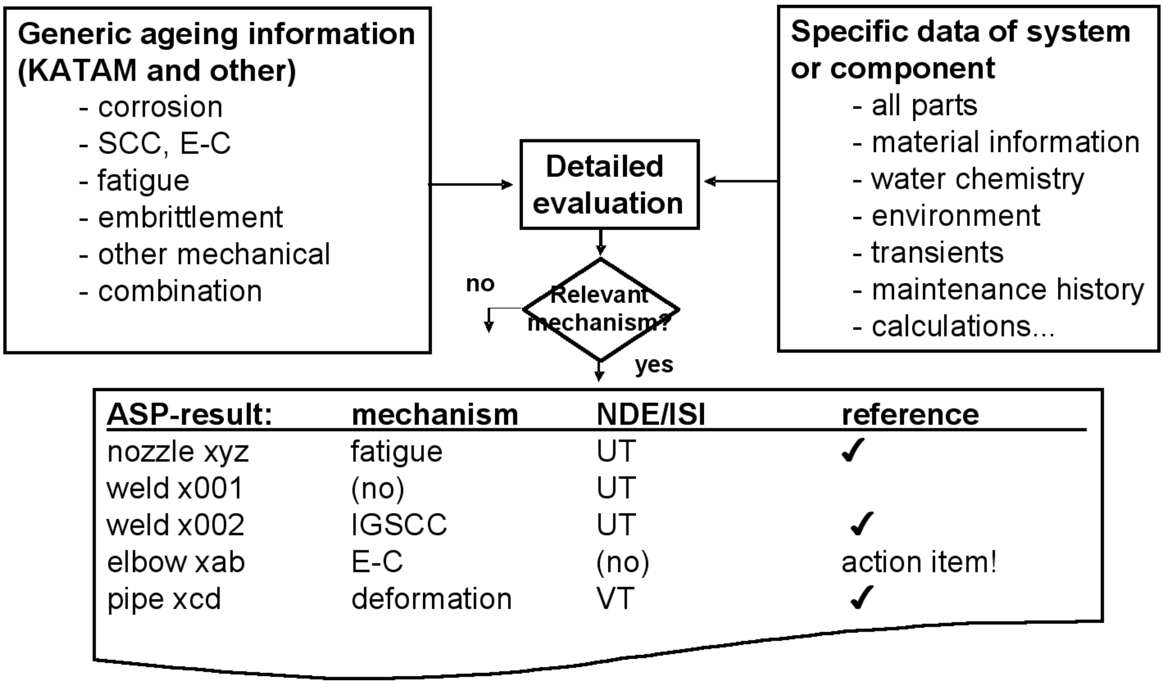

Figure 3: Evaluation of ageing susceptibility of mechanical components. Example of the summary of the results in the ASP documentation.

The ASP-results can be used for improvements in NDE and maintenance programmes in order to focus on the sites where ageing seems more likely than on others. The full documentation of the evaluation gives access to historical data of the system or component which is useful to the interpretation of findings. Besides NDE other measures in ageing surveillance may contribute to the actual knowledge of the state of a component.

Important elements of ageing surveillance of mechanical equipment are:

- maintenance programmes
- testing programmes according to technical specifications
- operational surveillance and walk downs
- in-service inspection (non-destructive examination, NDE) programmes according to the Swiss regulation NE-14 [3]
- transient bookkeeping for fatigue monitoring
- testing of surveillance samples for the assessment of neutron embrittlement of reactor pressure vessel steel
- control and surveillance of water chemistry
- various types of global condition monitoring, such as leakage detection

Possible additional activities are:

- instrumentation and temperature recordings in places where thermal fatigue may be relevant
- recalculation of fatigue usage factors based on measured transient data
- wall thickness measurement programmes in places where erosion-corrosion may be relevant
- enhanced or modified non-destructive testing programmes
- examination of material samples and other ageing studies

Supervision of ageing surveillance programmes

HSK reviews the ASP documents which are provided by the NPPs or by the Group of Swiss Nuclear Power Plant Operators (GSKL). HSK encourages the operators to work together in treating the NPP independent aspects of ageing. The HSK review is not only based on the plant specific ASP documents but also on the study of periodic reports, Inspections walk downs and periodic meetings of HSK and NPP specialists.

Application of the results of the ageing surveillance programme for mechanical equipment

In general all results of ageing surveillance have to be evaluated in the periodic safety reviews (PSR) that the NPPs have to undergo every 10 years or for purposes like power uprates or other licensing decisions. In the case of mechanical equipment there are the following special applications in the area of in service inspections.

Qualification of NDT Systems

The Swiss regulation for in-service inspections of mechanical components NE-14 [3] requires that non destructive testing-systems and -procedures (NDT) have to be qualified. Today qualification procedures are generally carried out in conformity with the "Common Position of European Regulators on Qualification of NDT Systems for Pre- and In-Service Inspection of Light Water Reactor Components" [4].

The needs for qualification are determined from the regulation as well as from the results of the ASP for mechanical components. The qualification procedure itself requires the definition of flaws which have to be detected and characterised by the NDT-system. Size, shape, and orientation of the flaws are input parameters for the design of test blocks for verification and blind tests under realistic testing conditions.

The ASP results identify the most relevant ageing mechanisms. From this the types of flaws are determined that should be used in the qualification procedure. From historic data of the component and from the documented evaluation of maintenance experience it can be seen if flaws have already been found or if manufacturing flaws that are left in place might play a role in ageing considerations. Fracture mechanics and additional data on the growth rate of flaws lead to flaw sizes that must be found in order to make sure that the flaw can not grow to critical sizes within the next testing interval. Since real findings of flaws caused by ageing are rare, test blocks with simulated ageing damage are vital in the training of personnel.

ISI-Programmes

The current Swiss regulation NE-14 for in service inspections [3] requires a basic programme for the nuclear pressure retaining equipment, but also makes use of the knowledge of ageing mechanisms in the area of equipment of safety systems (safety class 2 and 3). It provides a limited inclusion of risk considerations for safety systems of safety class 2, based on engineering judgement. Depending on a damage index S and a consequence index K the testing category of a component is defined according to table 2.

Damage index S:

- I: operating conditions of the system may lead to cracks or wall thinning
- II: system is in continuous or nearly continuous operation, but no damage mechanism is expected
- III: system is not in operation most of the time, and no damage mechanism is expected.

Consequence index K (consequences of component failure):

- A: substantial deterioration of safety functions
- B: minor deterioration of safety functions

Table 2: Testing categories of the pressure retaining components of safety class 2 systems

K (index of consequences)	S (damage index)		
	I	II	III
A	high	high	low
B	high	low	low

Testing category "high" requires ISI programmes with volumetric NDE methods, testing category "low" consists mainly of ISI programmes with visual testing and walk downs.

Future applications

In Switzerland risk informed ISI (RI ISI) is studied in pilot projects for the purpose of possible applications in the future. The Swiss ASP provides access to data on the relevant ageing mechanisms, on material data and on the history of the component in many respects (construction, testing, maintenance, and operation). These data have to be included in the application of the chosen procedure. If there are different views in the relevance of ageing mechanisms between the statements of the vendor's method and the statements of the ASP these differences have to be analysed and the application procedure has to be adjusted accordingly. The principal steps of a possible RI-ISI application are illustrated in Fig. 4.

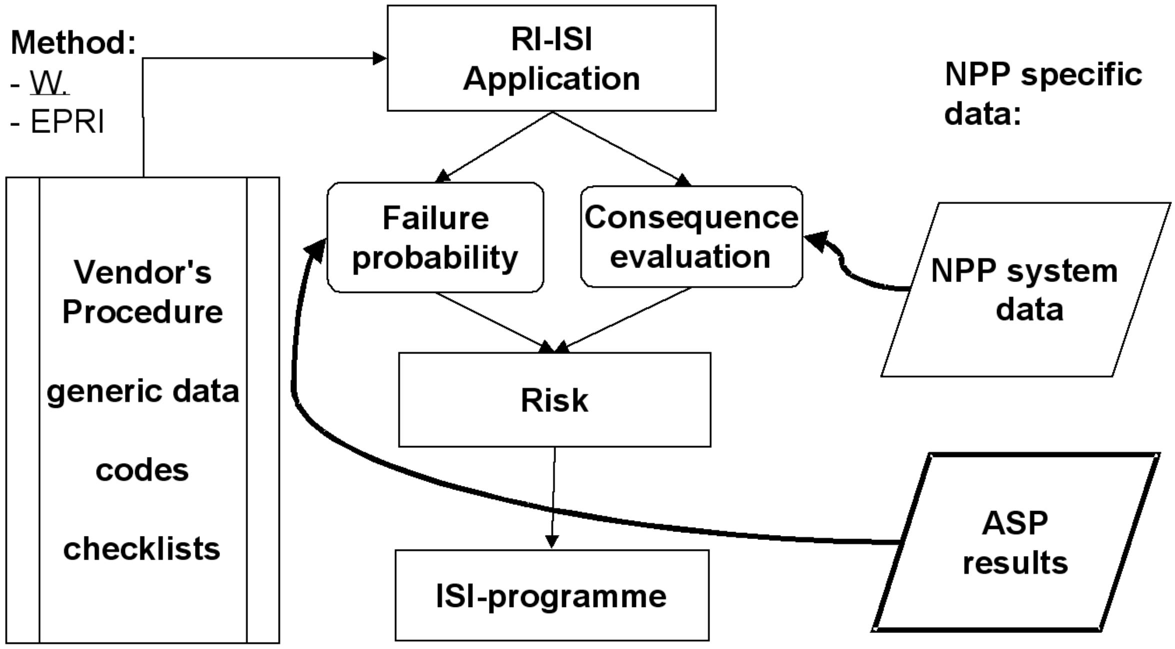

Figure 4: Role of ASP results in the application of RI-ISI methods (pilot studies).

Conclusions

Although the elaboration of the ASPs in Swiss NPPs was time consuming and bound a lot of resources, especially in the beginning, the effort pays back in many respects. Systematic procedures are established in order to determine the current state of ageing of all important parts of the Swiss NPPs and to support the planning of maintenance and ISI-programmes for mechanical and electrical components and for civil structures. Data needs for PSRs, for the qualification of NDT-systems and for the development of RI ISI applications are satisfied. Although the ASP focuses on material ageing there are useful side effects that address other ageing phenomena. Historical information is made available from the archives (document ageing), young personnel learns about the history and operating experience of old components and systems that are still in use (personnel ageing). The ASPs are an asset for the safe operation and for plant life management in the future.

References

[1] HSK-Guideline HSK-R-051/d "Alterungsüberwachung für mechanische und elektrische Ausrüstungen sowie Bauwerke in Kernanlagen" (Ageing Surveillance of Mechanical and Electrical Equipment and Civil Structures in Nuclear Installations), November 2004

[2] S. F. Schulz and Ph. Tipping, Kerntechnik 67 (2002) No. 4, 158-162

[3] SVTI-Festlegung NE-14, Wiederholungsprüfungen von nuklear abnahmepflichtigen mechanischen Komponenten (Swiss regulation for in-service inspections of mechanical components in nuclear power plants), Rev. 6

[4] Common Position of European Regulators on Qualification of NDT Systems for Pre- and In-Service Inspection of Light Water Reactor Components, EN-NRWG, EUR 16802, Rev. 1