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Application and Importance of Ageing Management in Plant Life Extension Programme, Swiss NPP's

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1. Summary

In December 1991 the Swiss Federal Nuclear Safety Inspectorate (HSK), concerned with aging and consequent safety aspects in the nuclear plants, requested the utilities to commence a systematic review of all safety relevant components and building structures regarding effects of aging and to set up an aging management programme (AMP). This programme should address the structures as well as the mechanical and electrical equipment of the plants. It has to be shown, that at any time operating the plant, the safety margins will be untouched by aging degradation of components and structures.

To fulfil this requirement a Swiss Utility Working Group (GSKL) for Ageing Management was installed. The scope of a Swiss AMP was defined and in the meantime the key guideline documents have been prepared.

The scope of these activities does not only serve the important aspect of reliable plant service but also facilitates component and plant life extension feasibility. The older plants have been operated now for up to 30 years, so plant life extension (PLEX) will become a more important topic for plant life management (PLIM) of the Swiss NPP. It is very encouraging, that there is an official memorandum of the Swiss authority with the clear statement, that they could not identify any technical reason, why the older plants should not extend their design life for at least 10 and the younger for 20 years.

The result of this is that a well established AMP provide a good basis for a long term safe operation (LTO).

The operating life-time for nuclear plants in Switzerland is principally not restricted by time-limited operating licenses. The licensing authority requires that the utilities report periodically the plants condition in order to prove that the safety requirements are still fulfilled. All Swiss NPP's have to perform Periodic Safety Review (PSR) every 10 years. The PSR in Switzerland must content (Regulatory rules, Guide HSK-R-48):

- Actually safety concept incl. updated Safety Analysis Report (FSAR)
- Judgement of operating management and operating experiences
- Deterministic safety analysis
- Probabilistic safety analysis

⇨ **AMP is a very important part of plant life management**

We see the Swiss AMP not only for its own purpose but also as a link to other programmes such as the probabilistic safety assessment (PSA). In setting priorities for SC2 and SC3 components, an important input is that information obtained from the PSA. For the possible implementation of risk informed applications such as RI-ISI, information such as degradation mechanisms resulting from the AMP can be applied in assessing failure potential in piping systems.

Key words: Ageing management, plant life extension programme, Swiss NPP's

2. Important Definitions in Ageing Management and Periodic Safety Review

An AMP deals with two types of changes in plant Systems, Structures and Components (SSCs) which occur with time and use and which may have an impact on plant safety and reliability. These are physical or material degradations and obsolescence owing to evolving technology and standards. These two elements of AMP scope – material ageing and technological obsolescence - are defined as follows.

2.1. Technological Aging

At the beginning of operation of a nuclear power plant, loadings, experience with the plant weak spots and other teething problems are recognized and can be remedied within the process of experience evaluation. This measure has the effect that general improvements in quality and safety levels take place.
In contrast to this, developments in the state of the art can result in existing plants leaving the ideals of current technology and that non-conformances are corrected or compensated by retrofitting.

We understand as the state of the art:

State of Science

Knowledge from research which is generally acknowledged or has been verified by other bodies (e.g. state supported research and published studies and reports).

State of Technology

- Relevant rules, regulations and standards
- Nuclear technological rules of the supplier of the nuclear plant
- Publications (fundamentals, requirements guides etc.) of the International Atomic Energy Agency (IAEA) and the International Commission for Radiation Protection (ICRP)
- Plant experience and realization of the State of the Art in other plants and relevant other branches of industry

Retrofitting measures taken should answer technological aging encountered as far as possible. As opposed to material aging* it is understood that it a measure to adapt to the State of the Art independent of the aging condition of the equipment.

This is only possible to adapt the State of the Art with certain parts of a plant. Examples of this are fire-fighting and extinguishing systems, replacement of control systems, steam generator replacement in PWR plants etc.

For deviations from design criteria which were valid at the time of construction such as design concerning internal and external events, choice of materials, number of redundancies in safety systems etc. compensatory measures may be necessary. Examples of such compensatory measures are: installation of supplementary systems or equipment, re-qualification of existing systems as far as possible etc. As a result of this older plants after a certain time, despite extensive retrofitting, never reach the 100% technological state of a new plant.

Within the limits of technological aging all e measures which can be realized must however be taken to reach the required safety standards of the whole plant based internationally accepted quantative risk criteria "core damage and emission frequency" established by means of risk analysis.

An integral evaluation of existing safety conceptions of the whole plant takes place within the scope of the periodic safety review (PSR).

By means of this the effectiveness of those measures introduced as a result of technological aging can be evaluated. Based on the results, in particular those from deterministic (DSA) and probabilistic (PSA) analysis further measures can be introduced if need be.

2.2. Material aging

Within the scope of material aging the life dependant physical and chemical processes are followed which can change the properties of a component, structure or the material used. With material aging the material undergoes diminishing quality and a reduction of the margin to the minimum design requirements.

If the expression remaining life is used in this context then the possible period of operation is meant until the minimum operational and design requirements are still met if an event occurs

Material aging phenomena are largely based on known facts and knowledge and are taken into account when planning maintenance, inservice inspection and functional testing.

3. Swiss Utility Working Group for Aging Management

To fulfil the requirement of the authority and to perform the first steps to reach this goal, a utilities working group was formed to set up a programme for a joint approach on material aging matters. This group defined the basics of the Swiss Aging Management Programme (AMP) and described them in several documents:

- **Programme for Reviewing and Optimising Aging Management Measures**
  This programme describes material aging phenomena encountered in nuclear plants and provides an overview of aging management measures. In addition the programme defines the objectives of the working group and the applicable technical fundamentals.

- **Catalogue of Ageing Mechanism (KATAM)**

This catalogue categorises the different aging mechanisms. It defines all types of aging encountered in light-water reactor plants together with interactions between material, environment, medium and mechanical loading. Component reviews are performed on the basis of these criteria and categories listed in order to determine the endangered regions.

The aging mechanisms for mechanical components are defined in a special catalogue. For electrical components the structure of the document is a little different because of the wide range of components involved. For this reason the catalogue constitutes part 1 of the electrical component „Steckbrief“.

For building structures the catalogue is issued as an Appendix to the guideline for preparing „Steckbrief“-file documents.

- **Guidelines for preparing component „Steckbrief“-files**

These guidelines are the working groups basic working document. They describe the methodical and technical approach for all three fields and aim at standardising reviews in the different plants. For the fields electrical components and building structures they are supplemented with special technical appendices, for example: aging modelling, thermal aging of polymers, useful life determination, detection methods, building structure anchors and interfaces in buildings, so that they can almost be considered textbooks.

- **Specimen „Steckbrief"-files for selected components**

These documents have been prepared as examples to assist a nd standardise the preparation of „Steckbrief"-files in the different plants. Safety class 1 components and buildings and electrical 1E qualified components, have been given the first priority. Specimen documents have been prepared for:

- Beznau NPP Reactor Recirculation System (mechanical component)
- Beznau NPP Reactor Building (building structure)
- Listing of all aging mechanisms which can be encountered in electrical components with details of detection methods. The various components are divided into groups such as cables, motors, transmitters, valve drives etc.

The group is divided into three subgroups, concerning with the aging of electrical, mechanical components and civil structures. So it was necessary to define the interfaces and the responsibilities of the groups and therefor an additional document was issued, the so called „interface document". The basis structure and the responsibilities are shown in figure 1.

After the four documents, listed on the page before, had been issued, the plants started to review their systems, based on these documents. It was the main target of the working group to fulfil the authority's requirements which are quoted as follows in the programme document:

Material aging management in accordance with the working group programme shall provide satisfactory proof that for all safety relevant components all known aging mechanisms will be taken into account in maintenance and quality assurance, and that measures will be taken for any omissions revealed.

In addition, aging management shall also provide a technical basis for optimising maintenance programmes, improving reliability of components and keeping maintenance costs down. One of the most important elements of aging management is condition monitoring to provide information on the present state of the component or building structure.

During the course of this work, utilities concerns on securing future electricity supplies for the Swiss market encouraged closer attention to aspects such as component life which has a direct effect on the life of the whole plant.

3.1. Status of the Work in the Group for Electrical Components

Due to the wide range of electrical components encountered, electrical components have been broken down into component groups such as cables, transmitters, motors, switches, contractors etc. all together 31 groups. This fact determined the structure of the „Steckbrief"-files.

Part 1: Aging mechanisms applicable to the component group
Part 2: Potential diagnostic methods
Part 3: Plant specific review of the components used in a component group taking into account the experience from the maintenance programme

The component reviews performed till now had shown that a greater part of aging management performed is actually an integral part of preventive maintenance measures.

The group is currently focussing on three items:

- **Maintenance rules:**

Updating of the current rules as a result of the aging assessments performed so far.

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- **Evaluation of the restlife of cables:**

Surveillance samples of various cables installed in older plants (Beznau and Mühleberg NPP)

placed in special exposed areas in the Containment for PLEX purposes.

- **Aging of polymers:**
Evaluation of a computer code for the determination of the aging of polymers.

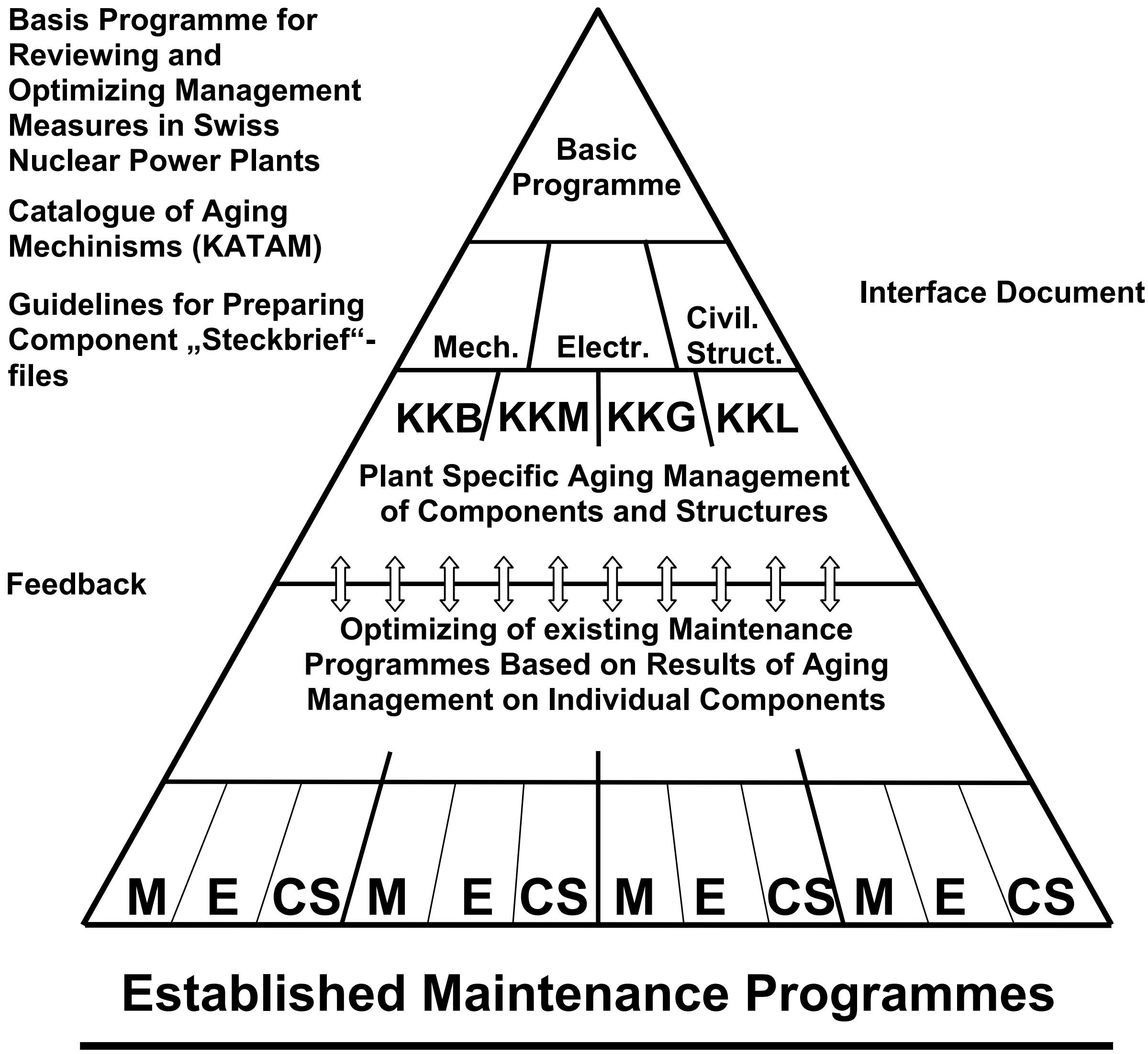

Figure 1: Basic Structure of Aging Management in Swiss NPP

3.2. Status of the Work in the Group for Civil Structures

The inspection programme defines the procedure for systematic monitoring of building structures and takes into account the special features of such structures. It provides for:

- **Baseline or principle inspections on the outside and inside**

These are performed at the beginning of the programme and are repeated after 10 years at the latest.

- **Intermediate inspections**

Documented findings from routine control rounds are summarised in a list after a period of 6 years after each principle inspection.

- **Special inspections**

These are inspections for which special measures are necessary such as use of special instruments. These inspections become necessary:

- when recommendations from findings during principal inspections require additional measures,
- when relevant changes of condition or behaviour of the structure, or of its usage factor have occurred or
- when special inspections are deemed necessary after a certain period of time to check the effectiveness of implemented maintenance measures.

Table 1 shows the four utilities with five plants in Switzerland and some typical experience related to the maintenance of their concrete structures. The completed repair and mitigation measures were taken mostly for preventive reasons.

Plant / Reactor Type	Startup / Age / Major Upgrades	Maintenance Experience		
		Building / Structure	**Degradation**	**Repair / Mitigation Measures**
Beznau Units I and II 365 & 357 Mwe PWR	1969/71 32/30 y NANO 1991/92	Reactor building - outer concrete shel - fuel pool - decontamination coatings Auxiliary buildings - roof insulation - penetrations fo pipings	- minor cracks due to shrinkage - borated water leakage - minor cracks due to shrinkage - humidity / cracks - splitting off	- no action required - helium leakage test - recoated - repaired - repaired
Mühleberg 355 MWe BWR	1972 29 years SUSAN 1989	Reactor building - roof (dome) - outer concrete wall - drywell structure Ventilation stack	- minor cracks due to shrinkage - sporadic corrosion of reinforcing bars due to insufficient concrete coverage - minor cracks due to shrinkage - cracks, bad compacted concrete	- new insulation - protective coating - crack monitoring - repaired; protective coating
Gösgen 970 Mwe PWR	1979 22 years	Reactor building - dome of outer concrete shell	- minor cracks due to shrinkage	- preventive maintenance: reprofilation and water repellent (hydrophobic) coating
Leibstadt 1145 Mwe BWR	1984 17 years	Reactor building - outer concrete shel - fuel pool - decontamination coatings Auxiliary buildings - roof insulation - penetrations fo pipings	- no degradation dark discolourings due to lichen were examined and have no influence on the quality of the concrete structure	- no action required

Table 1: Maintenance and repair experience in NPP concrete structures

The utilities group for the structural systems addresses the maintenance, surveillance, rehabilitation and documentation measures. The technical basis is given by the utilities experience, the aging management technology for non-nuclear structures and the international state-of-the-art, such as summarised by the International Atomic Energy Agency in IAEA-TECDOC-1025.

The GSKL-group worked out a Guide Manual which is controlling the procedures for concrete structures, steel structures, anchorage elements, fire proof closings and all types of interface elements. It serves as the common technical basis for all plants and for their structure specific aging management.

The Guide Manual provides the general procedure for condition assessment and documentation. It supplies as technical attachments a catalogue of degradation mechanisms, the available inspection methods and the criteria for classifying the condition of the investigated structure. Figure 2 shows the structure of the Guide Manual and some representative features.

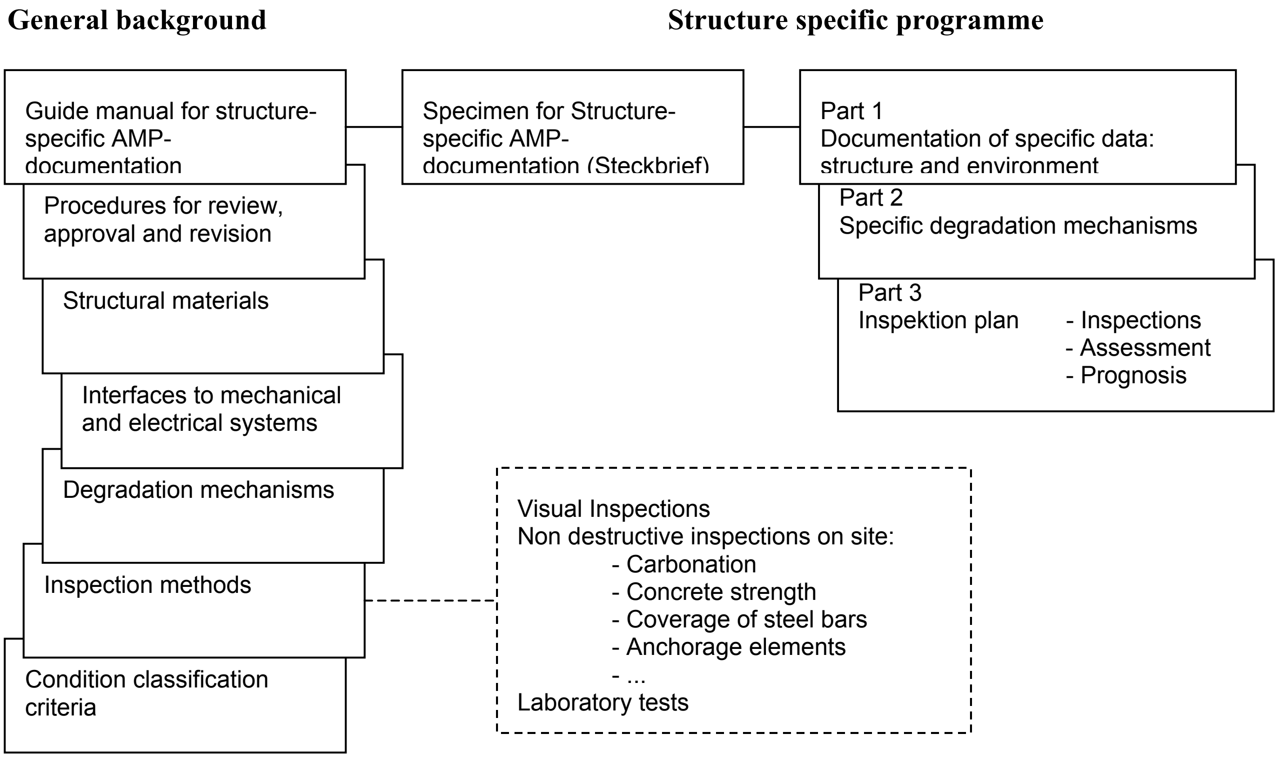

Figure 2: Guide Manual (Leitfaden) for the aging management of safety related structures

In general the complete visual inspection is the first step to the condition assessment. Further more detailed investigations are required where failures are detected or where the visual assessment is not conclusive.

Special investigations or repair actions are required for cases where the acceptance criteria are not fulfilled. The acceptance criteria for condition assessment were subject of controversial discussions with authority representatives. They are specified case-by-case, considering the safety and aging relevance of the structures. In most cases the acceptable condition of the investigated structure is or will be specified to be either class 2 or 3, within the overall range of 1 to 5, defined by typical damage patterns (type and amount of cracking, corrosion, etc). Figure 3 gives the logic background for this decision. The acceptable condition has to be specified considering the expected degradation curve, the inspection interval and the functional limit of the specific structure.

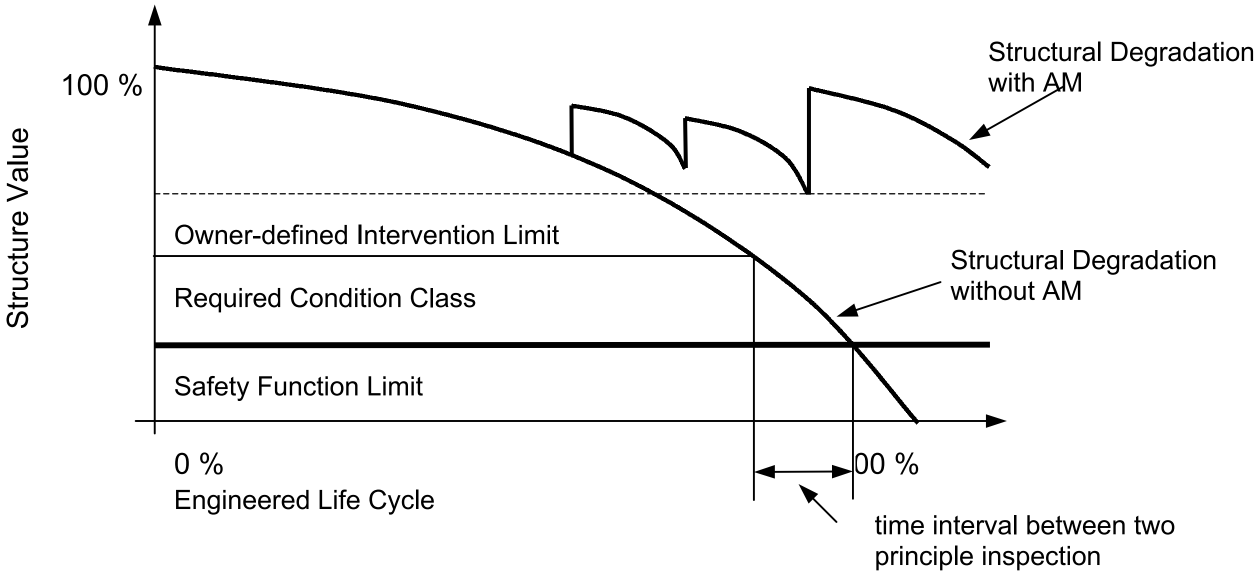

Figure 3: Specification of acceptable condition class, based on degradation curve

State of Practice

As an immediate measure the utilities are collecting the material fragments becoming available from construction works. The fragments are stored as a source of information on aging related properties.

Basic inspections have been completed and documented for the reactor buildings in all of the five plants. In some cases restoration measures were taken for concrete structures, as indicated in table 1. Table 2 highlights the state of current practice.

Plant	AMP-documents (Steckbriefe)	Inspections for condition assessment
Beznau Units I and II	All 26 planned documents finished	The inspection programme has been started, it is planned to finish the basic inspections by July 2002
Mühleberg	All 22 planned documents finished	The inspection programme has been started, it is planned to finish the basic inspections within 4 years
Gösgen	All 24 planned documents finished	The inspection programme has been started
Leibstadt	26 of 46 planned documents finished	The inspection programme will be started next year

Table 2: Overview of the state of practice for structural Condition assessment

The completed inspections and the condition assessments come up with results in the range of expected degradation. So far all detected degradations have been mitigated with commonly applied repair technology.

The current understanding is that the service life of the plants will not be limited by degradation of the concrete structures. The concrete aging is considered to be manageable with a rigorous and systematic inspection and rehabilitation strategy.

3.3. Status of the Work in the Group for Mechanical Components

In the mechanical group the work in the first phase was focussed on the assessments of the systems and components related safety class 1. In the meantime more or less all these systems are finished.

3.3.1. Example for an assessment, Reactor Pressure Vessel Mühleberg NPP (KKM; figure 4 & 5):

From the point of view of aging management the reactor vessel is quite a complex component. This is because of the large number of parts and materials involved and the varying mechanical and thermal loadings and radiological exposures encountered in service. In addition local effects of service and other transients have to be taken also into consideration. For this reason each part was identified and evaluated separately for possible occurrence of anyone of the aging mechanisms listed and defined in the KATAM.

Furthermore the component service history and the evaluation of occurrences in this and in other

similar plants were documented and analysed. All these data accumulated were documented systematically in a special component aging report. Of all the aging mechanisms considered only five of these were determined as relevant for the vessel and for subsequent evaluation in greater detail, these were:

- intercrystalline corrosion cracking
- stress corrosion cracking
- fatigue corrosion
- fatigue caused by service transients
- neutron embrittlement

One of the important conclusions drawn from the study was that the reactor vessel is in a condition to perform its safety function over a greater period of time than that of the 40 years determined by analytical design methods. This fact means that there is nothing against formally extending the life of the vessel.

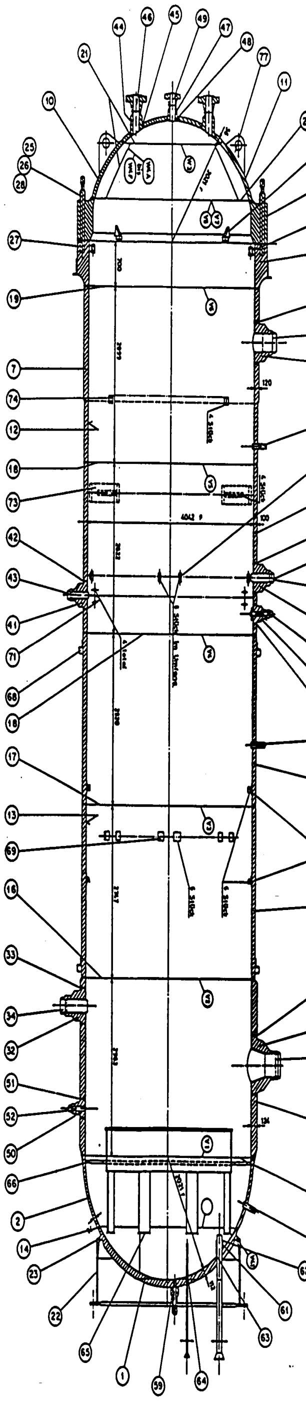

Figure 4: Rector Pressure Vessel Mühleberg NPP

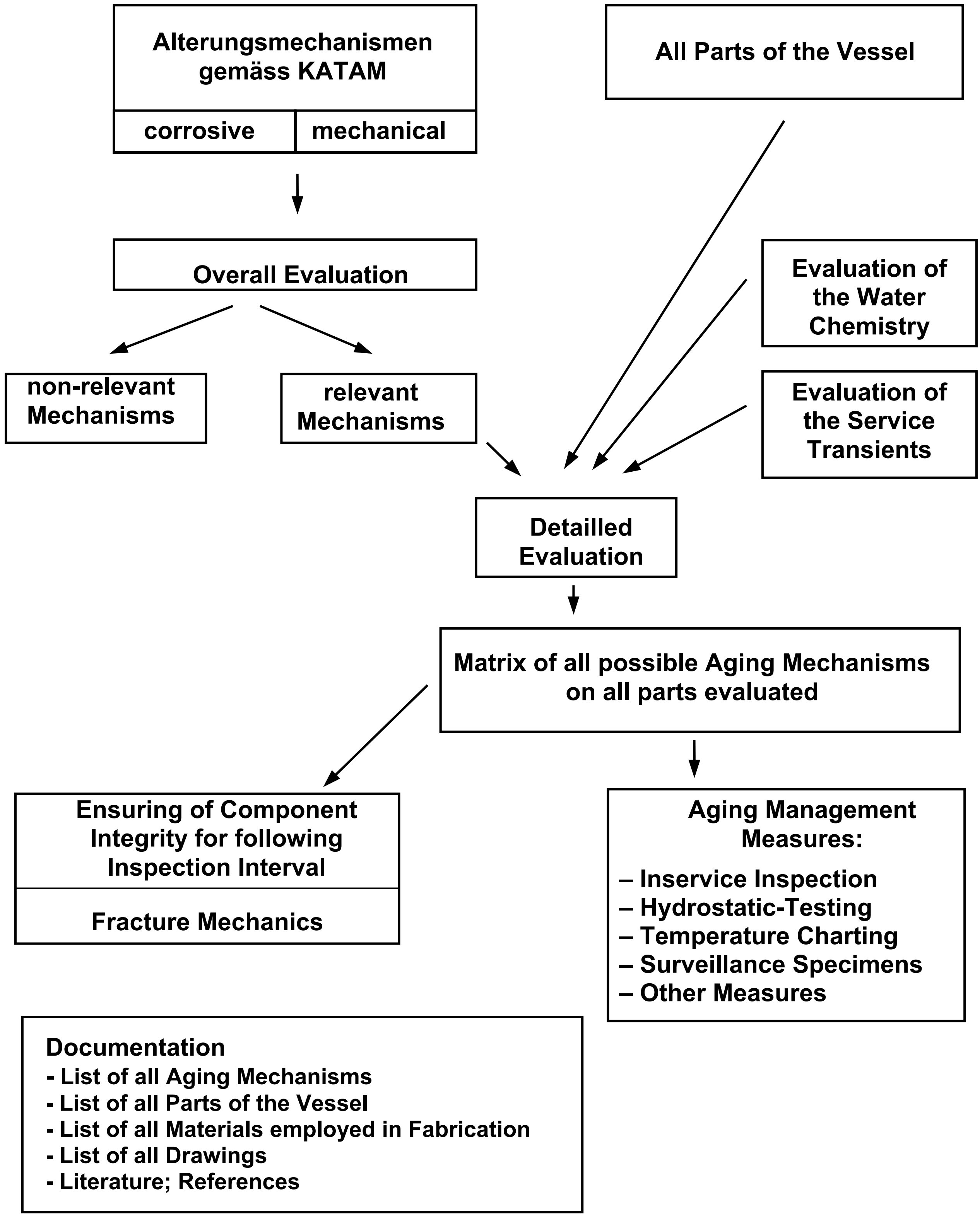

Figure 5: Flowchart for the review of the KKM RPV

After finishing the works on components of SC1 systems we started to discuss, how we could manage the assessments of SC2 & 3 components. It was a reasonable amount of work we spent so far for SC1 and it is our goal to reduce this work. The problem was that we have much more components related SC2 & 3 than SC1. So we need to find some reductions and we want to do this in two ways:

(1) Prioritisation of the Components

(2) Generic „Steckbrief"-file on the basis of materials used under our plant-specific operational conditions

3.3.2. Prioritisation:

For a reduction we have to find a valid selection method, which will be approved by our authority, this means, we must:

- identify all safety significant components
- get approval by the authority
- get considerable reduction of manpower
- use existing data's
- easy to use

The way we want to make it is as follows and we will:

- include all SC1 components
- include all NE-14 category 2.2 (Swiss maintenance rules)
- use PSA data's to identify the most safety significant components
- get input from system engineers
- get input from radiation specialist
- get input from operation engineers
- look at the main function of the system

<u>1. Step</u>

Identify SC1 components (e.g. plant database)

<u>2. Step</u>

Identify NE-14 cat. 2.2 (e.g. ISI documents)

<u>3. Step:</u>

We have to make a ranking with the method of PSA and we defined the following criteria:

FV > 1 E-3 and
FV < 1 E-3 & RAW > 2 component included in the AMP

FV < 1 E-3 & RAW < 2 component not included in the AMP

(FV = „Fussel Vesely importance" and stands for the contribution of a component for the core damage;

RAW = „Risk Achievement Worth“ and stands for the factor the risk of core damage would increase under the assumption, this component would definitely fail compared to the normal failure rate)

4. Step:

We get the input from the several engineers.

5. Step:

After we have got the ranking and the input from the other disciplines (system engineer identifies his most important components from his point of view,...) we mark the identified components (this are all "active" components) in the P & ID. Now we need the „passive“ components, the pipings and we look at the main function of the system. This means, an emergency system has the function to bring water from a tank to the reactor pressure vessel and we take all the pipings into the aging management programme, that are necessary for identified „active“ components to fulfil their function. These pipings are the mainlines. Additionally all components in this mainlines will also be put into the AMP. Offgoing lines from the mainlines less 1/10 of the mainlines-diameter are not included, bigger lines are included to and with the first isolation valve. Finally all components identified by PSA, system engineer, radiation specialist, operation engineer plus the ones necessary to fulfil the function of the system are included in the AMP.

With the pilot-study of the Leibstadt NPP for the system "High Pressure Core Spray" (HPCS) we got a reduction of about 80 percent. From totally 252 components we came down to 43 after the assessment.

3.3.3. Generic Documents

- We identify all materials used for components (Pumps, valves, pipes, heat-exchangers,..) in our plants.
- We identify all operational conditions (water chemistry, temperature, pressure,..)

This will be limited numbers for the materials and then operational conditions as well. Then we make assessments for all these materials under all operational conditions and report the results in the generic „Steckbrief“-file for materials. For all these identified aging mechanism we will make recommendations for the necessary maintenance and inspection works to prevent failures.

With this document as basis we make the specific review of the identified components and we look for components that use materials with identified aging mechanisms under our conditions. Then we check our specific maintenance programme for this component and compare it to the recommendations. Depending on the findings we have to set corrective actions on our maintenance programme or not.

The "prioritisation method" as well as the "generic documents" are quite simple ideas, we are currently in the phase of finishing the pilot-study and beginning with the generic document. We cannot say, this is the 100 percent final versions, we know there is space for improvements, which we plan to make when we go on with the practical work of the assessments. Both methods can only work, because we can rely on a very good basis. This means excellent maintenance and inspection programmes, excellent performance, and consequent efforts to keep the plant in good technical shape (e.g. backfitting of additional emergency systems in the older plants)

As additional information all the plants work on procedures and regulations how to implement the aging management in the plant organisation. This is necessary, because till now we spent the most effort on the assessments of the components. But it is also important to implement the aging management programme as a living programme; this means we have to install automatisms for the interdependence of the AMP and the maintenance.

3.4. New Programms

3.4.1. Risk Informed Inservice Inspection (RI-ISI)

In the last 3 years in Switzerland two pilot studies were started to prove the advantages of „Risk Informed Applications. At KKL the EPRI methodology is used. This methodology uses mainly two elements, called „consequence analysis“ and „failure potential analysis“. The second one has to be seen as the results coming from the AMP, because the AMP as well as this part of the RI-ISI identifies these parts of the systems, where we have to assume the potential of degradation mechanisms, which stands for a higher potential of component failures (e.g. pipe ruptures). So the information's coming from the AMP can be used as input for the RI-ISI.

Combining AMP, PSA and ISI, improves the value of each single application, leading to a much more powerful tool, than the single ones. This helps to improve the processes for maintaining safety and reliability of the Swiss NPPs.

Figure 6 shows the EPRI risk matrix, Risk Category (RC) 1 – 3 means 25 % inspection / 10 years, RC 4 – 5 10 % / year, RC 6 – 7 no inspection.

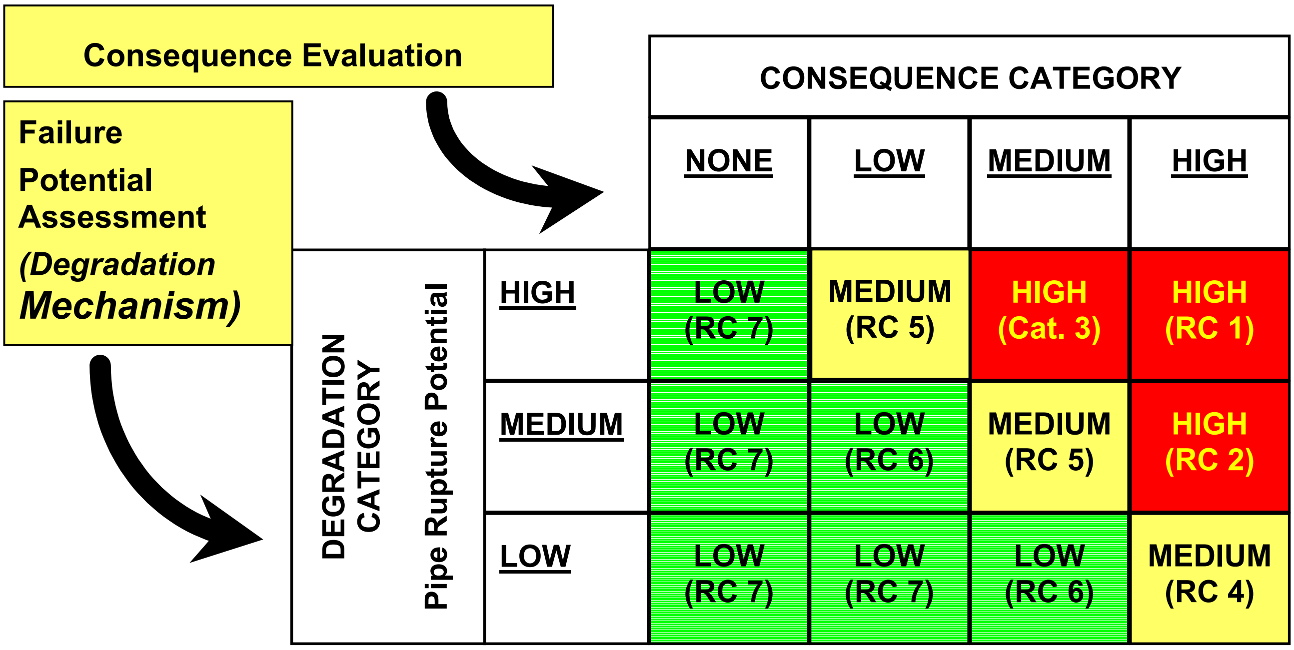

Figure 6: RI-IS diagram, EPRI methodology

4. Participation in IAEA-Programme "Assessment and Management of Aging of Major Nuclear Power Plant Components Important to Safety" work

The Swiss utilities working group also participates since ten years in the above mentioned programme. This provides us with the opportunity for a wide, high level international exchange of technical information. Emphasis has been put on the established working groups for the following documents:

- **Safety Series:**

- No. 15 “Implementation and Review of Nuclear Power Plant Ageing Management Programme”
- No. 3 “Equipment Qualification in Operational Nuclear Power Plants: Upgrading, Preserving and Reviewing”

- **TECDOCs for:**
  - PWR Reactor Pressure Vessel
  - PWR Primary Circuit
  - PWR Steam Generators
  - BWR Reactor Pressure Vessel
  - BWR Reactor lnternals
  - BWR Metal Containments
  - Concrete Containments

Parallel are two specialist groups involved in Aging Management for Concrete Containments and for Review, Upgrading and Maintaining Electrical Equipment Qualification.

5. Conclusions

- The Swiss AMP has to be seen as a long term operation programme and a very important part of PLIM
- Considering economics we intend to operate the plants up to 60 years
- Actually results show the good conditions of the Swiss NPPs, supporting this goal