ADVANCED LIFE-CYCLE MANAGEMENT FOR AN INCREASED STEAM GENERATOR PERFORMANCE

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ABSTRACT

High steam generators performance is a prerequisite for high plant availability and possible life time extension. During operation, the performance is reduced by fouling of the heating tubes and by corrosion, resulting on a reduction of the heat-exchange area.. Such steam generator degradation problems arise from mechanical degradation and a continuous ingress of non-volatile contaminants, i.e. corrosion products and salt impurities accumulated in the steam generators. In addition, the tube scales in general affect the steam generator thermal performance, which ultimately cause a reduction of power output. AREVA applied an integrated service for utilities to evaluate all operational parameters influencing the steam generator performance. The evaluation is assisted by a systematic approach to evaluate the major steam generator operational data. The different data are structured and indexed in a C*leanling-Matrix*. The result of this matrix is a quantified, dimensionless figure, given as the *Fouling Index*. The *Fouling Index* allows to monitor the condition of steam generators, compare it to other plants and, in combination with a life-time management applied at several German utilities, it allows verified statements on the past operation. Based on these data, an extrapolation of the potential additional life-time of the component is possible. As such, the *Fouling Index* is a valuable tool concerning life-time extension considerations. The application of the cleanliness criteria in combination with operational data with respect to life-time monitoring and improvements of steam generator performance are presented.

INTRODUCTION

The steam generators (SG) of pressurized water reactors (PWR's) join the nuclear island with the secondary cycle. As such, the SG's are key components which have a large impact on the plant performance.

During operation, SG's are subject to mechanisms which have an impact on the component life-time. An important aspect is the deposition of scales on the heating tube which reduce the heat transfer capability. Tube corrosion in addition leads to wall degradations and in consequence to tube plugging which decreases the heat transfer area. Both mechanisms are promoted by unfavourable feed water chemistry in combination with the cleanliness of the secondary cycle. The heating tubes usually are the focus of maintenance and surveillance measures, since these parts of the SG's are prerequisite for a reliable power output as well as for an effective radiation barrier. Concerning the component life-time also the feed water nozzle has to be considered. Especially during the start-up and shut-down procedures of a power plant the feed water nozzle is subject to large thermal gradients which cause thermal fatigue of the nozzle material.

During the last years AREVA NP has started a series of R & D projects to investigate the different parameters which influence the life time of SG's. Further attempts have been made to quantify these parameters in order to facilitate statements on the actual condition of the individual component. Especially the *Cleaning-Matrix* in combination with a plant specific life-cycle management shall assist utility operators to plan long-term actions.

PARAMETERS INFLUENCING THE SG LIFE-TIME

The life-time of SG's is basically determined by two parameters. One is the thermal margin given by the excessive heat transfer area, the other is the fatigue of the main feed water nozzle. The actual heat transfer area margin is influenced by tube scaling (fouling) during operation and tube plugging. Both effects reduce the thermal performance. Tube plugging is carried out when the tube walls show degradations larger than a specified limit (i.e. 50 %) of the initial wall thickness due to corrosion. Figure 1 gives an overview of the main parameters influencing the SG life time.

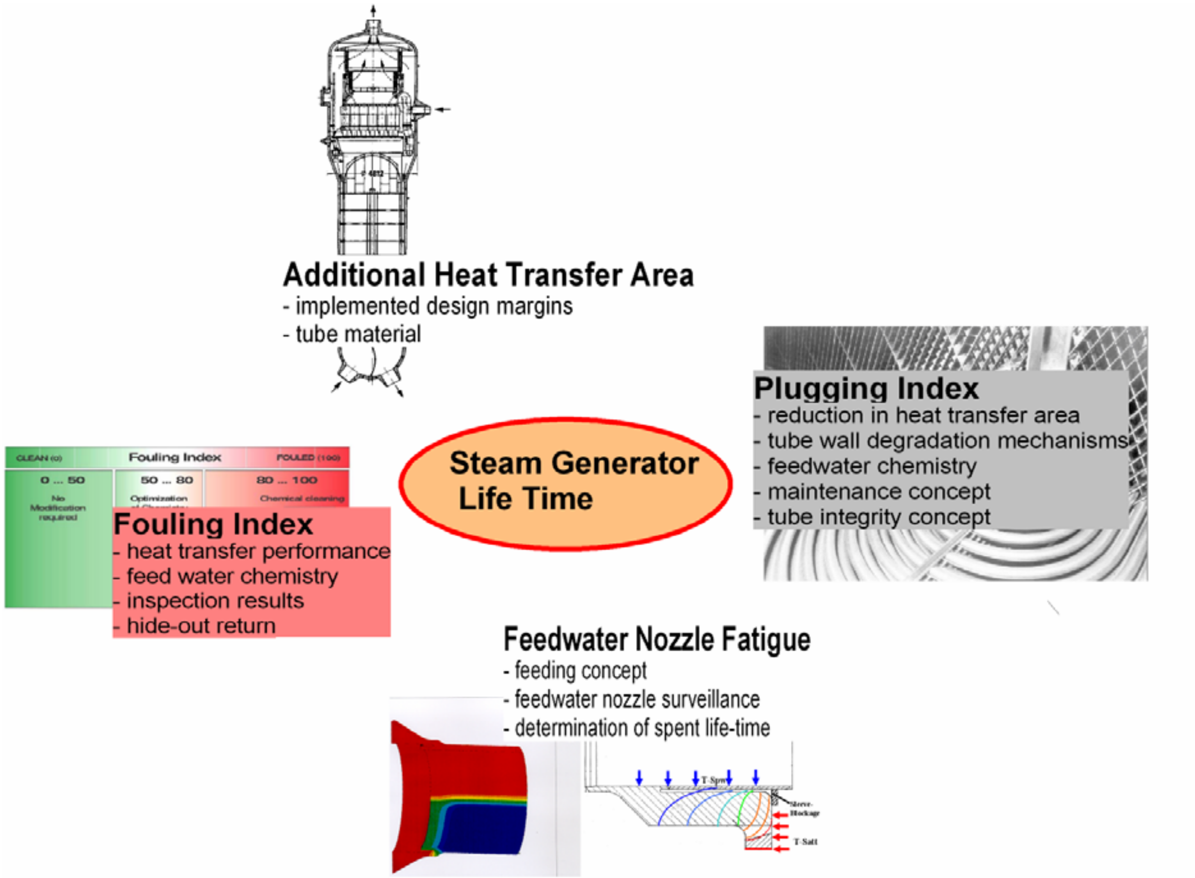

Figure 1: Main Parameters for the SG life-time

Excessive heat transfer area is usually added as a margin to the heat transfer area required by the designed thermal power. It takes account of the potential degradation of the heat transfer area during the life time of the component.

The *Fouling Index* takes account of the thermal performance of the SG's. Depending on the tube scaling, the fouling factor, the reduction of the heat transfer area and the reduction in steam pressure can be determined. Basis are operational data such as steam pressure, primary temperatures. In order to derive information on measures required to maintain the SG performance, the data is supplemented by further data such as feed water chemistry, iron ingress and NDT inspection results. In order to combine these different parameters which have an influence on the SG cleanliness, a *Fouling Index* has been introduced by AREVA NP to facilitate the interpretation by a quantification the operational parameters.

The *Plugging Index* is subject of current R&D activities. Besides a constant thermal performance, the SG life-time is strongly dependant on the tube integrity. Within the steam generator service the NDT inspection results are analysed and interpreted with regard to the corrosion mechanism, the relation to other indications and the SG cleanliness. The amount and the cause of plugged tubes is continuously recorded. The aim of the *Plugging Index* introduced by AREVA is to quantifiy and to relate the impact of the tube plugging to the *Fouling Index* in order to combine all parameters influencing the SG lifetime.

The last parameter which may restrict SG life-time is the feed water nozzle fatigue [2]. Due to the large temperature difference between the saturated water in the downcomer and the cold feed water, the material is subject to possible loadings resulting in thermal fatigue. It has been AREVA NP practice to monitor the temperatures on significant locations in the nozzle area by the FAMOS system [4], [5]. From these measurements, feeding concepts, which minimize the nozzle fatigue, are adapted to the plant’s requirement.

For the implementation of an effective life-cycle management the combination of the major parameters *Fouling Index, Plugging Index* and feed water nozzle fatigue in combination with a long-term condition monitoring is essential in order to achieve information of the appropriate maintenance actions. On a yearly basis the relevant parameters and analysis results are recorded and evaluated to achieve a comprehensive data base for the development of the component condition:

- Heat transfer performance
- Feed water chemistry parameters
- Tube bundle inspections and NDT results
- Fatigue analysis
- Comparison with the operational experience and from other plants

Depending on the results actual trends can be observed and appropriate measures can be planned in due time. As a consequence, damages can be minimized, outage times are reduced and the life time of the component can be extended.

LONG-TERM TREND ANALYSES

Within AREVA NP’s integrated steam generator service concept relevant operational data, supplemented by additional pressure and temperature recordings of sensitive areas are analysed and long term trends are derived from these data. Without comprehensive expert knowledge, involving different faculties a derivation of appropriate measures to counteract negative trends may be rather difficult. An example is given by the development of the Fouling Factor over the operation time. Figure 2 shows the development of the Fouling Factor in two nuclear power plants with pre-heater type steam generators. The SG’s in plant A were cleaned after 13 years of operation after a steep increase of the fouling factor the year before. After the cleaning the fouling factor increased. The real cause, however, has not been an increase of tube scales but the scavenging of the concentric gaps between heat exchanger tubes and pre-heater, which impair the overall heat transfer capacity, as also described in [1] in more detail.

Depending on the feed water chemistry, the gaps get blocked with increasing operation time and the Fouling Factor decreases again. Plant B was cleaned after 24 operational years. Here, the effect is even more significant. Another measurement after 2 months already shows a steep decrease of the Fouling Factor. Further mid-term measurements confirm this trend.

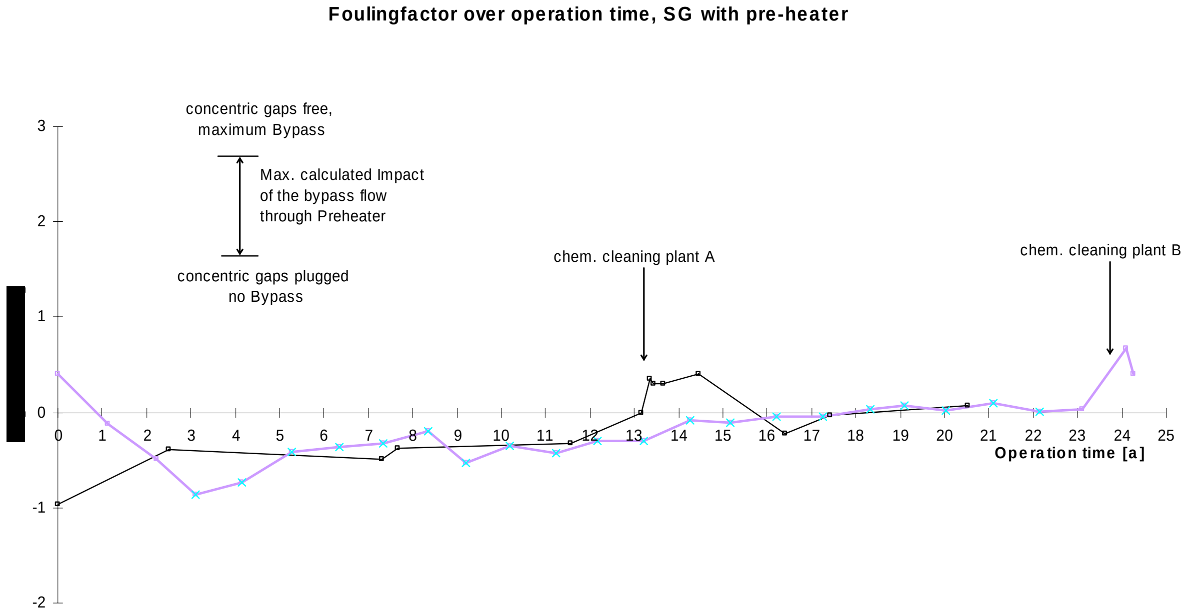

Figure 2: Development of the fouling factor in two plants, equipped with pre-heater-type steam generators

Figure 3 shows the behaviour of the Fouling Factor after a chemical cleaning of a typical feeding design SG. In 1987, only one SG was cleaned. This resulted in a significant reduction of the fouling factor. After the chemical cleaning of all SG's in 2002 the Fouling Factor was reduced substantially to a fouling factor determined shortly after the commissioning of the plant. In this plant the effectiveness of the chemical cleaning is directly observable from the development of the *Fouling Index*.

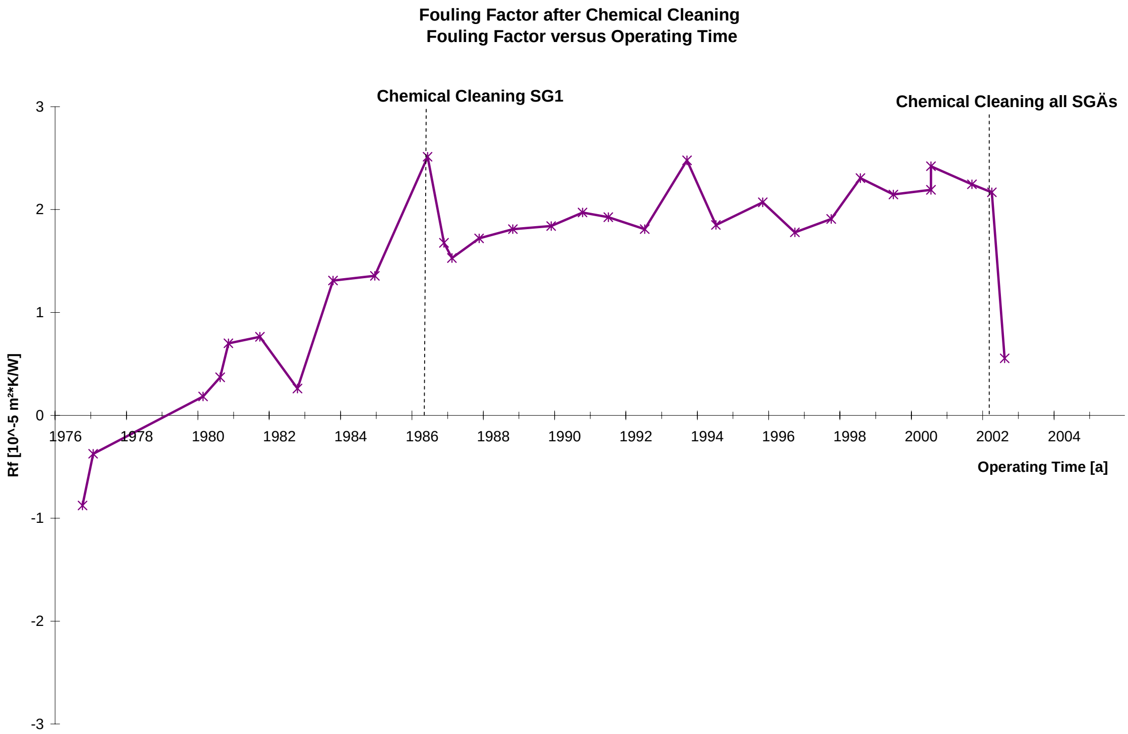

Figure 3: Plant C, showing the development of the fouling factor in a plant without pre-heater, started with phosphate treatment

In Figure 4 the long term trend of the Fouling Factor of two plants with different feed water treatment is shown. One plant started the operation with a phosphate treatment of the feed water. After approximately 10 years, is was switched to an H-AVT treatment. The other plant operated with H-AVT treatment from the beginning. As consequence, the increase of the Fouling Factor in the plant starting under phosphate treatment is very steep. After switching to H-AVT, there is less increase of SG fouling. Plant's operating in H-AVT environment from the beginning show very low SG fouling with the mean value remaining approximately constant over the whole operation time.

The two examples on the thermal performance show that it is very difficult to interpret single results without information on further parameters. In this respect, the increase of the fouling factor after a chemical cleaning of a pre-heater SG has to be anticipated and as long as the increase is within the calculated range, no measures are required. Also the plant history is important to know, as the example of the different feed water treatment shows. Apparently, there are many more parameters which have to be considered in order to derive a suitable and appropriate maintenance strategy.

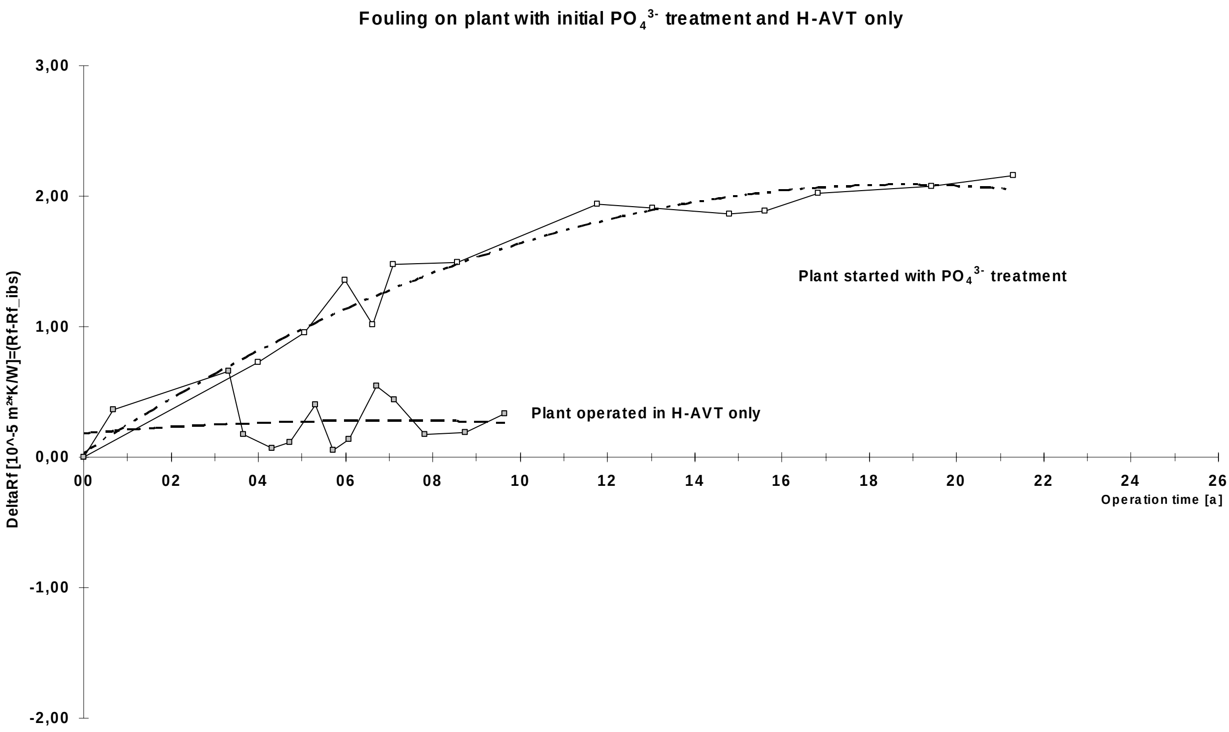

Figure 4: Different development of the fouling factor depending on the feed water chemistry

Figure 5 shows how iron ingress influences the heat transfer performance. Both parameters show the same trend over the operation time. The chemical cleaning resulted in an large decrease of the fouling factor and of the iron inventory as it is usually the case after chemical cleaning of feeding design SG's.

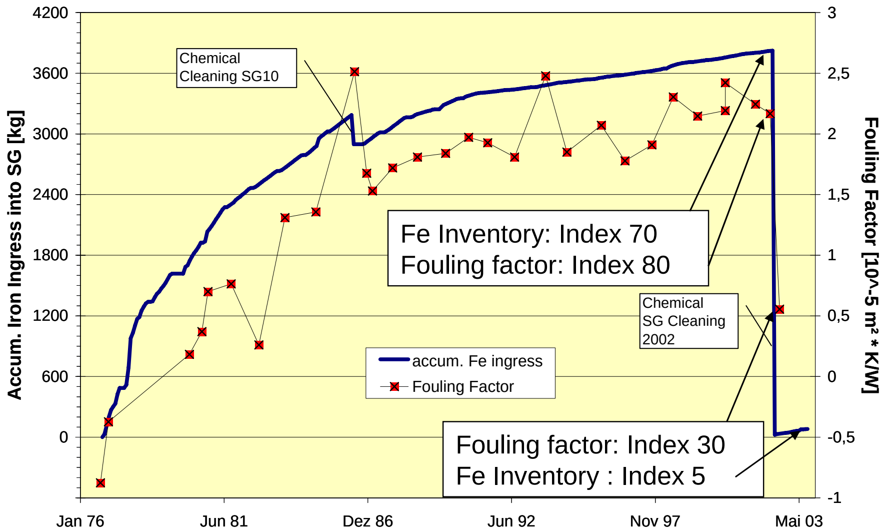

Figure 5: Correlation of the fouling factor with the iron ingress, example plant C

i	Indicator Parameters	Weighting
	Heat transfer performance	**30%**
1	Fouling factor	9%
2	Heat transfer margin	**...**
3	Growth rate	**...**
...	...	
	Water chemistry parameters	**30%**
	N2H4 Ratio	6%
	SG deposit loading	6%
	Hide-out behavior	8%
	Hide-out return behavior	10%
	...	
	Tube sheet deposits	**15%**
	Number of tubes affected	**...**
	Sludge height	**...**
	Colors of sludge deposits	**...**
	...	
	Tube sheet lancing history	**15%**
	Quantity removed	**...**
	Density of deposits	**...**
	Composition of sludge deposits	**...**
	...	
	Tube scale measurements	**10%**
	Scale thickness	**...**
	Appearence, colors	**...**
	...	
n	...	**100% Sum**

Table 1: Example of the weighing factors of the single parameters

In order to quantify the impact of a single parameter on the SG heat transfer performance, AREVA NP made several attempts based on long-term records. With these, the single parameters are indexed as shown in Figure 5 for the Fe inventory and the fouling factor. These parameters represent a mean value derived from the operation experience of a range of plants. Based on this experience, weighing factors have been introduced in order to relate each index to its overall impact on the heat transfer performance and SG condition as shown in Table 1. The result is a single value which quantifies the actual thermal performance of each SG in a nuclear power plant.

In order to maintain the steam pressure, this is a useful tool, since it indicates the reason for heat transfer degradation by tube scaling and allows the implementation of counter measures in an early phase of degradation.

Considering life time extension, the *Fouling Index* is supplemented by further parameters which contain information on the actual mechanical integrity of the component. This is a view beyond the thermal performance since life-time counter measures on life-time limiting trends require a long term planning of appropriate maintenance measures. Therefore it is very important not only to provide a broad data base but also a tool for interpretation to make the results also transparent for non-experts.

AREVA NP is therefore working on the provision of a tool which links the *Fouling Index* to other aspects influencing the SG life-time. In combination with the Fouling Index the impact on feed water feeding and nozzle fatigue as well as tube wall degradation are linked in order to get a reliable quantification of the remaining SG life-time. This enables transparent long-term decisions of the utility operators in order to maintain SG performance at an extended life-time.

SUMMARY AND OUTLOOK

The operation performance and the life time of steam generators in nuclear power plants are influenced by a variety of operational parameters. These are continously recorded and analysed within AREVA NP's integrated steam generator service. However, the parameters analyzed are interdependent and the results often require an expert knowledge to be correctly interpreted. To facilitate correct interpretation of the results and to make the interpretation of the results clearer for plant operators, the relevant parameters have been indexed and summarized by weighing functions to take account of the influence of the single parameter on the heat transfer performance. As a quantifiable value, the Fouling Index has been established. It reproduces the actual plant condition in respect of its heat transfer performance as shown in Figure 6.

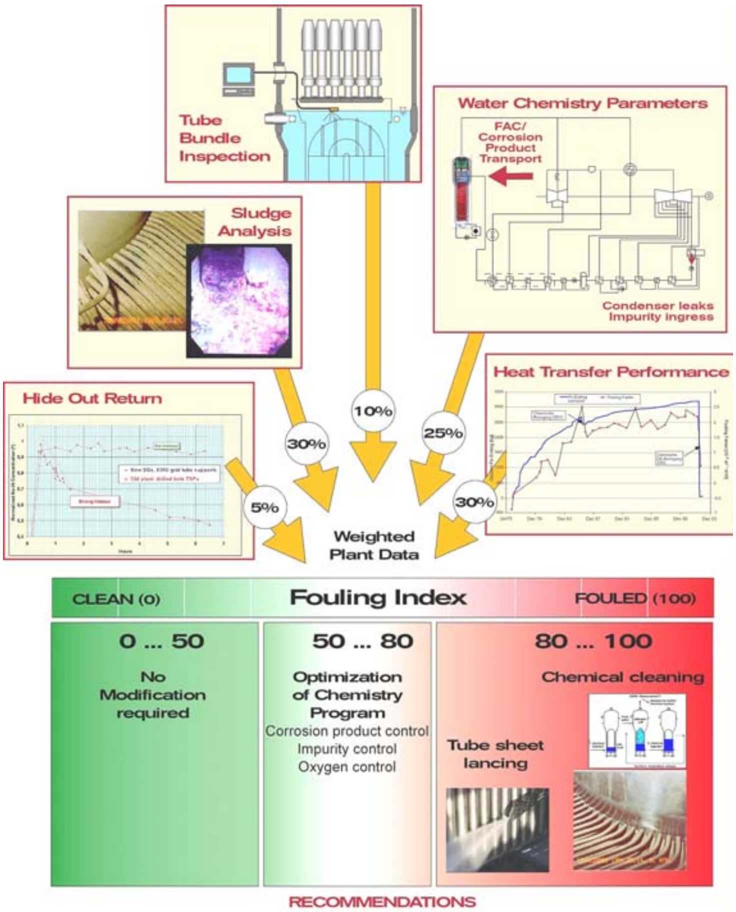

Figure 6: Composition of the Fouling Index based on single parameters

The result of the *Fouling Index* is a value on a scale 0 – 100. For values below 50, no actions are required. The range 50-80 indicates that future measured should be planned, for instance an adaptation of the feed water chemistry or the control of corrosion products. Values above 80 indicate the necessity of immediate actions in order to maintain or restore the heat transfer performance of the SG's.

As already shown in Figure 1 the *Fouling Index* obviously is only one of altogether three operational parameters which influence the component life time. Further R & D efforts of AREVA NP aim at a tool which integrates all three parameters whereas in current work, the thermal performance (*Fouling Index*) and the impact of tube plugging, together with the employed maintenance concept, is implemented with regard to assess the remaining margins of the heat transfer area. Besides maintaining the operational performance of the steam generators, a transparent life-cycle management is possible, facilitating the detection of weak points at an early stage. Remedial actions can then be taken anticipatorily

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