

Service life prediction of components and systems

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BACKGROUND

In many countries of the OECD member states the operating licences of nuclear power plants will expire about 40 years after their date of issue. The licenced operating period is derived from settings in the ASME Code, which might have been fixed according to an empirical basis and experiences with fossile plants taking into account some safety margin for uncertainties in nuclear applications (1).

It is obvious that there may be an economic impact if nuclear plant life extension allows nuclear electric generating units to continue to operate beyond their original 40 years licenced period (2), (3), (4). This question nowadays is strongly influenced by

- a serious acceptance crisis of nuclear energy and the necessary efforts for restoring lost confidence among the public
- the difficulty to achieve the licence for a new site for a nuclear power station caused by this acceptance crisis in the public.

Therefore, appropriate life-extending measures can be a way for the utilities to demonstrate safety and reliability of nuclear power stations in future, too.

In the Federal Republic of Germany an operating licence for a nuclear power station is not directly restricted in its exploitation by a certain number of years. But from the licencing point of view it must be kept in mind that the construction permits of all plants are based on documents, records and data in which an operating time of a plant of 32 years is assumed; in combination with a load factor of 0.8 German power plants require relicencing activities after an operation period of 40 years, too. However, the validity of the licence to operate a nuclear power plant depends essentially on the success to meet with the main demand of the German Atomic Law (5):

It is to provide by all technical and administrative efforts and measures during planning, construction as well as operation of the plant to bring and to keep all installations and procedures in a condition without exertion of risk to environment and public, judged on the basis of present state of science and technology.

Deviations from the licenced status of safety or new findings and settings in regulations and guidelines may lead to backfitting activities for the plant. If essential demands for the safety of components, systems or procedures are missed or if out of this intolerable risks arise for the health of public, the plant must be shutdown for corrective actions.

Therefore, if these general demands for the safe operation of nuclear power plants may be warranted, out of the German legal basis reasons for the restriction of the licence may not be derived. But our present experience shows that a new licence in combination with a legal public hearing will be necessary. The success of this procedure will be dubious if in the coming years no new nuclear power plant will be built and the state of science and technology is not obviously established.

EXPERIENCES

In a nuclear power plant a great variety of components must be kept in safe and reliable conditions. In order to predict the service life of the plant's components and systems all modes for the degradation of reliability must be considered. Table 1 shows typical influences due to aging and wear on components and systems. These influences are not of the same importance for all plant areas, but many degradation mechanisms are caused by designers, construction planning and the fabrication procedures in an early stage of the plant life.

The components which dominately control the plant life are those whose replacement or repair is difficult or impossible. A categorization on the basis of such aspects (1) is summarized in table 2.

However, the result of such a categorization strongly depends on conceptional items of a plant, which will be pointed out in this contribution.

The importance of such plant properties may be demonstrated by the replacement of the steam generators in the nuclear power plant Obrigheim which was realized within a quarter of a year approximately, Fig. 1. It can be shown that the best measures to extend service life of components and systems are based on lessons learned from events caused by failures.

In Table 3 some degradation mechanisms are attributed to the components and systems and their operational reliability. Further on, Table 3 gives reference to the main reasons by which deterioration phenomena are operative. Most of the degradation mechanism shown in Table 3 are important for the long term integrity of pressurized components. Each aspect in this concern must be considered in order to predict service life of components and systems.

The experiences with operating plants and the assessment methods to evaluate the integrity of the pressurized components of watercooled reactors have influenced guidelines and regulations in the Federal Republic of Germany in recent years to a great extent (6).

One of the results of these efforts, essential for service life prediction of components and systems, is the cumulative usage factor resulting from specified loadings due to transients for a modern plant design as shown in Fig. 2. It can be show that the results influence the activities for in-service-inspections an their frequencies.

CONCLUSIONS

1. The knowledge about the history of technology and the experiences with operating nuclear power plants show that the service life of a plant is basically determined by economic considerations.

2. The basis for life extension of nuclear power plants will derived from experiences with operating plants within the next ten years. It must be demonstrated that the basic design (software) of a complex plant will be kept in mind within two generations of operating staff.

3. There is no chance to operate a plant-Methuselah without planning and building up new plants.

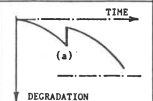
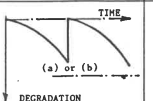
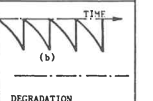
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Table 1 Influences of aging and wear

	DEFINITIONS	TYPICAL INFLUENCES
AGING	CHANGE OF SPECIFIC PROPERTIES OF METALLIC OR NONMETALLIC MATERIALS DEPENDENT ON BOTH - ENVIRONMENTAL INFLUENCES - TIME	LOADING COLLECTIVE, RESULTING LOCAL STRESSES FATIGUE AND CRACK FORMATION CHEMICAL COMPOSITION EFFECTS IN CONJUNCTION WITH NEUTRON IRRADIATION AND FRACTURE TOUGHNESS THERMAL AGING CORROSION AND CRACK GROWTH RATE IRRADIATION-ASSISTED STRESS CORROSION CRACKING (IASCC)
WEAR	PROGRESSIVE LOSS OF MATERIAL FROM THE SURFACE OF A SOLID BODY CAUSED BY THE MOVEMENT OF ANOTHER BODY (SOLID, LIQUID, GASEOUS)	FRICION EROSION, EROSION-CORROSION (FRETTING), PITTING, WASTAGE, CREVICE FORMATION

Table 2 Categorization of components for service life prediction

	CATEGORY 1	CATEGORY 2	CATEGORY 3
ATTRIBUTE REPLACEMENT REPAIR CONTROLLING QUALITY	DIFFICULT, IMPOSSIBLE POSSIBLE ENGINEERING LIFE (SERVICE LIFE)	POSSIBLE POSSIBLE ECONOMIC LIFE	PLANNED -- NO DIRECT RELATION TO SERVICE LIFE
EXAMPLES	REACTOR PRESSURE VESSEL CONCRETE STRUCTURES ELECTRIC CABLES	STEAM GENERATORS HEAT EXCHANGERS PIPING ETC	PUMP-, VALVE- INTERNALS FUEL ASSEMBLIES CONTROL RODS, DETECTORS ETC.
TYPE OF DEGRADATION			

a): repair
b): replacement
-----Limitation (safety)

Table 3 Origin of degradation mechanism

	DEGRADATION MECHANISM	INFLUENCED COMPONENTS AND SYSTEMS	CAUSED BY
(1)	IRRADIATION EMBRITTLEMENT	REACTOR PRESSURE VESSEL (RPV) INTERNALS OF RPV	DESIGN, MATERIAL, IMPURITIES IN STEEL (COPPER, PHOSPHORUS)
(2)	FATIGUE, CORROSION FATIGUE	PIPING AND ITS FITTINGS AND SUPPORTS, NOZZLES, VALVES, MIXING REGIONS OF FLUIDS WITH DIFFERENT TEMPERATURES	RESULTING LOCAL STRESSES, OPERATIONAL LOADING, SYSTEMS ENGINEERING
(3)	GENERAL CORROSION, FITTING, WASTAGE	SYSTEMS WITH LOW VELOCITIES OF FLUIDS, CONDENSATE IN STEAM LINES, SERVICE WATER SYSTEMS, SAFETY INJECTION SYSTEMS, INTERNALS OF PUMPS AND VALVES	SYSTEMS ENGINEERING, OPERATIONAL INFLUENCES, CREVICES (DESIGN), MATERIALS
(4)	STRESS CORROSION CRACKING (SCC)	WELD VICINITY IN COMPONENTS (STAINLESS STEELS), STEAM INDUCED FERRITIC PIPING/HIGH TEMPERATURE AND OXYGEN-CONTENT OF FLUID)	MATERIAL, OPERATIONAL CONDITIONS, OF CHEMISTRY CONDITIONS, INSULATION AND CASKET MATERIAL
(5)	WELD RELATED CRACKING, HYDROGEN EMBRITTLEMENT	ALL KIND OF WELDS, INTERFACE BETWEEN STAINLESS STEEL CLADDING AND VESSEL MATERIAL	STEEL-COMPOSITION AND MANUFACTURING PROCESS
(6)	EROSION-CORROSION	STEAM AND FEEDWATER PIPING, STEAM SEPARATORS, HEAT EXCHANGERS, TURBINE BLADES	CHEMISTRY CONDITIONS (PH-VALUE) MATERIALS, SYSTEMS ENGINEERING

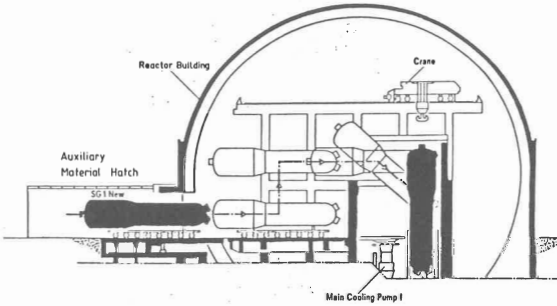
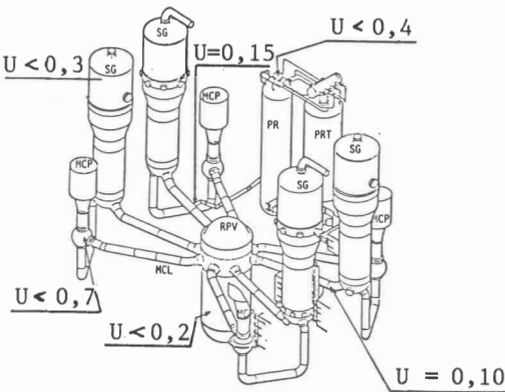


Fig. 1 Nuclear power plant Obrigheim, Installation of SG 1 (New)



RPV = REACTOR PRESSURE VESSEL
MCP = MAIN COOLANT PUMP
MCL = MAIN COOLANT LINE
SG = STEAM GENERATOR
PR = PRESSURIZER
PRT = PRESSURE RELIEF TANK
U = USAGE FACTOR

Fig. 2
PWR-fatigue analysis,
usage factor for main
components