SOME POWER UPRATE ISSUES IN NUCLEAR POWER PLANTS

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Issues and themes concerned with nuclear power plant uprating are examined. Attention is brought to the fact that many candidate nuclear power plants for uprating have anyway been operated below their rated power for a significant part of their operating life. The key issues remain safety and reliability in operation at all times, irrespective of the nuclear power plant's chronological or design age or power rating. The effects of power uprates are discussed in terms of material aspects and expected demands on the systems, structures and components. The impact on operation and maintenance methods is indicated in terms of changes to the ageing surveillance programmes. Attention is brought to the necessity checking or revising operator actions after power up-rating has been implemented.

KEYWORDS : Nuclear Power Plant Power Uprates, Degradation Of Steam Dryers, Regulatory Aspects

1. INTRODUCTION

The world's demand for energy is increasing as the growth in human population has gone from about 1.5 billion in 1900 to nearly 7 billion in 2008. This approximately 5 times increase has brought with it more demand for energy to satisfy the requirements of industries that manufacture goods and services for the growing population. This demand for energy, up to now, has been created largely by the so-called developed countries. In the future, as less developed countries undergo industrialization and create export-based economies and achieve higher standards of living, it is expected that the demand for energy will also increase. This effect is already being observed in various countries in Asia such as China and India. Until the so-called "oil shock" in the early 1970's this fossil-based commodity provided a seemingly inexhaustible and cheap supply of energy. Notwithstanding political developments from the 1970's to present, fossil-based fuels have greatly increased in price, have become harder to find and transport and bring with them issues concerned with ecological impact. The Kyoto Protocol from 1997 highlighted problems deemed to be a result of pollution through "greenhouse gases" and countries signatory to the Protocol undertook to reduce such emissions. It seems logical to replace fossil-based fuels, which are finite resources, with other types of energy, whether nuclear, solar, tidal or wind. To this end, it is logical, economically viable and ecologically responsible to keep all existing "fossil-free" energy sources and options operating for as long as possible, providing they can do so safely. Power uprates (PUs) of nuclear power plants can furnish a valuable contribution to increase the portion of non-fossil based energy resources.

This short overview discusses the way nuclear power plants (NPPs) may be modified or operated to increase power with due regard to keeping the systems, structures and components (SSCs) within their design and safety limits, taking into account observed and expected demands on the equipment involved [1]. The reason why NPP PU can be attractive to operators and utilities can be argued in terms of costs (it is potentially quicker, easier and cheaper to uprate an existing plant rather than to build a new one).

Many utilities are now expecting to operate their NPPs up to 60 years, or more, after having undergone rigorous regulatory control to ensure the SSCs fulfil all safety requirements. This depends on the actual NPP license status and conditions (i.e. re-licensing according to the American practice, or permission for continued operation using the current license, subject to periodic safety review every 10 years, mostly followed in Europe). The possibility of increasing power output of a given NPP will depend on various factors, ranging from core layout, design and equipment procurement aspects, overall economic viability and the results of comprehensive safety analyses. Also, a NPP is likely to be amortised during the last few years of its final operation, thus making it economically attractive for stake-holders, but the safety case must always have priority over the business case. Correct attention to servicing, maintenance, inspection, monitoring, replacement and refurbishment of the plant's SSCs, having due respect to changed operational parameters, is essential to the overall safety and economic success of PU.

2. NUCLEAR POWER PLANT UPRATE DEFINITION AND CATEGORIES

Power uprates of NPPs are a way to increase generating capacity in an economical and emission-free way. A more enriched uranium fuel is usually used to increase the core power of a given NPP. Fuel designs that effectively eliminate so-called "early burn-out" have been tailored to support extended PUs. This fuel creates more thermal energy and, eventually, more steam. This steam is then fed to the turbine generators to produce electricity. A variety of SSCs must then be able to cope with this increase in the flow-rate of steam and water. This may necessitate replacement of SSCs.

A NPP PU may be defined as the process of increasing the maximum power level at which a commercial NPP may operate. However, the term "Nuclear power plant uprates" may be a misnomer, in some cases, since the act of "up-rating" may only mean raising the power to the originally planned or designed rating anyway. The level of up-rating could therefore be seen as being relative to the current output. The three basic categories of NPP PU are currently understood as: 1. Measurement uncertainty recapture power uprates (MUR); 2. Stretch power uprates (SPU) and 3. Extended power uprates (EPU).

2.1 Measurement Uncertainty Recapture Power Uprates (MUR)

These PUs are typically up to 2 percent and are mostly achieved by improved techniques for calculating the reactor power. Small but cumulative enhancements, such as improved feed-water flow measurement are used.

2.2 Stretch Power Uprates (SPU)

These PUs of up to 7 percent are achieved without major plant modifications. Instrumentation set-points are adjusted to achieve the higher power.

2.3 Extended Power Uprates (EPU)

These are characterized by power increases of up to 20%, and involve significant investment into the balance of plant equipment. Large items, such as turbines, generators and transformers are usually involved in the task. Extended PUs therefore require extensive plant modifications in order to facilitate and handle the enhanced level of power produced. They are most often performed on boiling water reactors (BWRs) since such designs have more operational margins present.

3. EXPECTED EFFECTS OF POWER UPRATE

Power uprates, together with long-term operation (i.e. operation in excess of the nominal design life), are ways to increase the overall profitability of a NPP whilst ensuring continued energy supplies. However, plant equipment ageing rates in specific SSCs may increase, relative to those known, or anticipated, prior to the uprating. This is due to the fact that higher temperatures, pressures and coolant/steam flow rates are features of PUs. The NPP life-management system must therefore be modified to take into account the new system operating conditions. Furthermore, the frequency, scope and depth of inspections may have to be revised to ensure that the SSCs are "fit for service".

Since increased flow-rates of high pressure steam and coolant are a part of PUs, it is necessary to identify which actions, and in which time intervals, the operating personnel will have to perform in the case of plant anomalies arising during operation. Times allowed for manual actions to be implemented over automatic ones will be impacted by the change to the balance of plant due to PU.

In order to follow material effects of PU, it is essential to recognize how the changed operating conditions can affect SSCs. An obvious parameter to consider is the flow rate of coolant or steam. Apart from increased turbulence, which could potentially affect erosion-corrosion rates, secondary effects such as the change of frequency of cyclic loading due to vibration or thermally induced fatigue may cause an increase in the rate of degradation. Steam dryer cover plates in BWRs have cracked due to increased vibration associated with the higher steam throughput [2]. A further aspect is the presence of loose parts in the primary circuit, coming from failed components. Such debris have a potential to impact fuel assemblies and cause further damage. Loose part retrieval is, however, a fairly commonplace task and the detection and retrieval systems well-proven.

3.1 A Power Uprate Example in Switzerland

The NPP Leibstadt is a General Electric Boiling Water Reactor (BWR/6-238 with Mark-III Containment), which went into commercial operation in December 1984. The original reactor power was 3012 MW(th). One year later, the reactor power was increased by about 4 % to 3138 MW(th). This could be classified as a SPU, which could be easily accomplished because the BWR/6 design included this margin.

The standard BWR/6 was anyway designed for a reactor power of about 3600 MW(th), i.e. the PU of NPP Leibstadt was well within the design basis of the BWR/6. The safety assessment showed that most of the safety systems, such as the emergency core cooling systems, were already designed for the PU. Minor plant modifications were required, such as a modification of the blockage of the Automatic Depressurisation System and a feed-water pump run back during an anticipated transient without scram (ATWS), to improve the plant behaviour.

However, in comparison with the standard BWR/6 the NPP Leibstadt reactor core is smaller: it comprises 648 instead of 748 fuel assemblies. This implies a higher power density (62.8 MW/m3).

The regulatory authority, HSK, restricted the initial PU of Swiss NPPs to steps of about 5%. In fact, all NPPs in Switzerland have now undergone PU ranging from 5% to 19% (19% in the specific case for NPP Leibstadt). The reason for a step-wise 5% PU approach for the Leibstadt NPP was to verify by experience the expected plant behaviour during normal operation and by test programmes for each step during a minimum period of six months. Each step of the PU required a successfully performed test programme (turbine-, feed-water- and recirculation pump trips etc), normal operation without PU-related events and a plant performance report to the regulatory authority. The expert review concerning the Leibstadt NPP PU also addressed operator issues and times allowed for implementing actions.

In Switzerland, the regulatory guideline "Organization of NPPs" requires that before carrying out any technical changes to the plant, their effects concerning safety must be checked on and controlled [3]. Thereby possible impacts on human, technical and organizational aspects and their interaction must be taken into consideration.

4. DISCUSSION

It was assumed that since many NPPs were being operated below their design power, the act of PU would have no impact on safety or reliability of the NPP. However, certain problems arose, particularly with steam dryers in BWRs. It should be understood that the steam dryer is not classified as a safety-related component. Due to this, it has received less attention compared to safety-relevant components. However, the steam dryer in a BWR must maintain structural integrity in order to avoid that parts of it form debris and enter the RPV or steam lines and thereby potentially affect operation.

Nuclear power generation technology is continually evolving. Much has been learned over the last 60 years concerning materials in SSCs, their response to service conditions and operation. In particular, materials used for SSCs have been monitored closely to follow any changes they may undergo with respect to degradation caused by operational conditions. The main goal continues to be maintaining the integrity of the safety-relevant pressure boundaries in the primary circuit (reactor pressure vessel (RPV), piping, pressurizers and steam generator), as well as keeping secondary side equipment in good order so as to avoid forced outages connected with spontaneous failure. Such occurrences are usually costly in terms of lost power and replacement of affected SSCs. Remaining on the secondary side, the generating equipment (turbines and generator) and the distribution lines must also be maintained and designed to handle the increased output of the nuclear plant.

The process of PU has been a feature of the nuclear power industry since the 1970's. A number of PU-related events have taken place that could be traced to inadequacies in appreciation of possible effects and challenges to both plant and personnel. Notwithstanding any extra degradation caused by PU, it should be remembered that cracking of BWR internals, for example, continues to be a worldwide issue. Furthermore, it is not easy to relate any failure rate, which would have occurred anyway, to those failures observed after PU. It is only possible to state that certain problems in BWRs have occurred within relatively short times after PU was implemented. Concerning steam dryers, available literature on PU provides some of the following examples from the USA:

a) Quad Cities Unit 1 BWR NPP had been under EPU operation for about 1 year when significant cracking was discovered in the steam dryer hood. Furthermore, a piece of the outer vertical plate was missing. At the same time, a pilot vent line on a main steam relief valve (SRV) was found to be sheared off and the solenoid actuator for the SRV was damaged. Some collateral damage occurred to the main steamline supports.

b) After just 90 days of EPU operation of the NPP Quad Cities Unit 2, the steam dryer cover plate disintegrated and pieces of it were found on the steam separators and in the main steam-line. Approximately a year later, the steam dryer hood, internal braces and tie bars all failed.

c) Dresden Unit 3 was shut down for inspection after 10 months of EPU operation. Through-cracks, 10 cm long, were present in the steam dryer hood. Additionally, 2 feed-water sampling probes were found in the feed-water sparger.

There are other examples, showing where cracking took place near to gussets, where weld on stiffener plate was cracked and tie-bar welds had fractured. In some cases the damage had occurred on previously repaired areas. The physical causes for the degradation stem from the effects of coolant or steam flow-through. This induces high cycle fatigue through resonance, acoustics and pressure fluctuations. Design has also played a role, since it was found that steam dryers with square hoods were more stressed compared to those featuring curved hoods and thus exhibited more cracking. Units having small bore steam lines experience relatively higher steam flow due to a PU compared to those having larger bores. Therefore, depending on the level of PU and design of the NPP, the relevant SSCs may experience higher levels of loading that may cause increased rates of degradation.

Mitigation and repair of PU-induced degradation has been focussed on increasing the thickness of steam dryer cover plates and outer hood plates and by the use of full-length gussets on vertical plates instead of braces.

5. CONCLUSIONS

Nuclear power plant PUs have been a feature of NPP technology since the 1970's, but most implementations have taken place since the mid-1990's. However, problems have arisen in BWR steam dryers due to the increased flows, pressures and temperatures causing vibrations that have led to fatigue cracking.

Power uprate of NPPs is an action taken by owners and utilities to increase power in a relatively easy and economical way. Power uprate actions must be implemented in a logical and well thought out manner; regulatory approval is necessary if the balance of plant changes.

The inspection and ageing management strategies (plant life management programme) must be modified to take into account the possible effects of PU on ageing degradation rates and types in SSCs. High-cycle fatigue, vibration and acoustic effects must be monitored, and the frequency, scope and depth of inspection intervals optimized.

A NPP that is well-maintained, has a good safety record, and is reliable and economic to operate is likely to realize the full potential of any level of PU.

A PU will necessitate new analyses of human factors/reactor operator actions, especially those concerning ways to deal with transients or anomalies.

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