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IMPROVING NUCLEAR POWER PLANT'S OPERATIONAL EFFICIENCES IN THE USA

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ACRONYMS

ALARA - As Low As Reasonably Achievable
BOP - Balance of Plant
BWR - Boiling Water Reactor
CLTP - Current Licensed Thermal Power
EBR-1 - Experimental Breeder Reactor No. 1
EIA - Energy Information Administration
EPRI - Electric Power Research Institute
EPU - Extended Power Uprates
IAEA - International Atomic Energy Agency
INPO - Institute of Nuclear Power Operations
LAR - License Amendment Request
MUR - Measurement Uncertainty Recapture for Power Uprate
MWe - Mega Watt Electric
NRC - Nuclear Regulatory Commission
NEI - Nuclear Energy Institute
OLTP - Original Licensed Thermal Power
O&M - Operation and Maintenance
PCI-SCC -Pellet Cladding Interaction - Stress Corrosion Cracking
PWR - Pressurized Water Reactor
ROI - Return on Investment
SCRAM-Safety Control Rod Axe Man
TMI-2 - Three Mile Island Unit 2
U.S. - United States

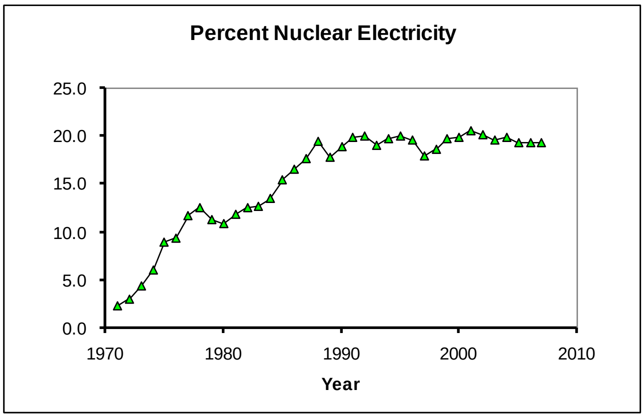
ABSTRACT

One of the primary reasons of the optimism for new nuclear plant construction progress in the U.S. is the significant increase in plant reliability and availability over the last 40 years. This paper provides insights on how the nuclear industry worked to improve the capacity factor and efficiency of nuclear power stations and ultimately reduce the cost to operate nuclear power plants in the U.S..

While the number of nuclear power plants in the United States has remained relatively constant for the past several decades, (the last nuclear reactor to begin commercial operation, Watts Barr, came online in 1996) the percentage of nuclear power in the national energy mix has increased, as shown in the Figure 1. (data from EIA)

Although a number of new plants came on-line in the 1970's and 1980's, a significant part of the increase in nuclear generation was achieved by a substantial increase in the overall capacity factor of the U.S. plants from about 60% in 1980 to over 90% today.

Figure 1 Percent of Total Electric Power Generated by Nuclear Power Plants in the U.S.

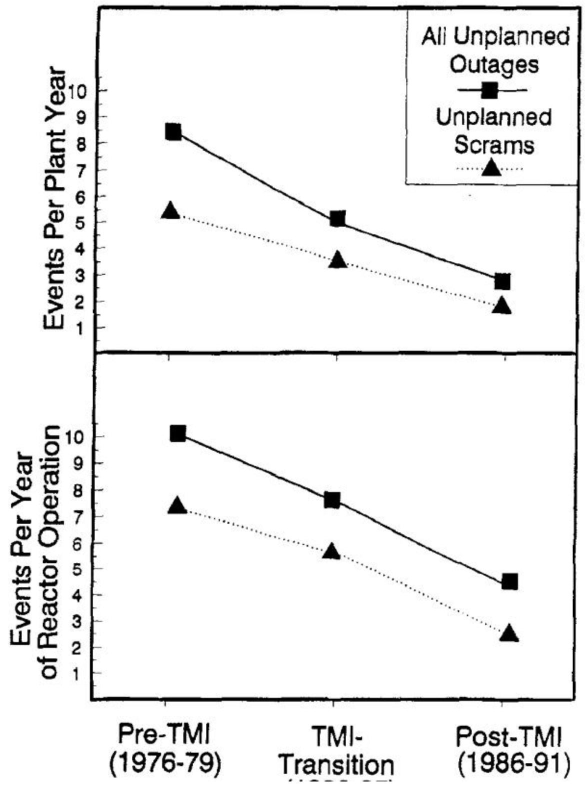


This large increase in capacity factor was achieved by reducing outages, extending fuel cycles, using higher burnup fuel, reducing unplanned outages and reducing the number of fuel failures. This increase in capacity factor combined with increases in power in various plants (power uprates) allowed nuclear power plants to maintain and increase their share of electricity generation. Such an increase in nuclear power generation is the equivalent of having built 25-30 nuclear power plants during that period.

The improvement of planned outage duration and unplanned outage frequencies improved during the last 30 years.

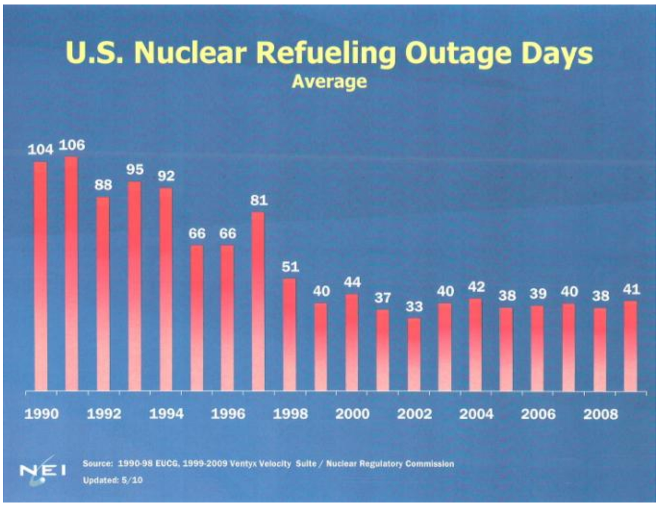
Figure 2 shows the reduction of unplanned outages from about 9 to 3 events per year from the time period of 1976-1979 to 1986-91, subsequently. Figure 3 shows the length of the planned outages reduced from 106 days for an average operating plant in 1991 to 38 days in 2008. The reduction in planned outage length and the number of unplanned outages represents a significant improvement in the reliability, cost and safety of nuclear power plants.

Figure 2 Unplanned Outages and Unplanned Scrams



Scrams for 47 Sample U.S. Plants (Ref. 1)

Figure 3 U.S. Nuclear Refueling Outage Days (Ref. 2)



Additionally, power uprate, which allowed plants to operate at a higher power, and power plant life extension, which extended the operating life of a power plant beyond 40 years, provided more electrical power to be generated at a reduced total production cost.

These initiatives and other cost and performance based programs improved the overall performance of nuclear power generation in the U.S. and has provided adequate improved cost and safety justifications for building more reactors in the U.S..

1.0 INTRODUCTION

One of the reasons for the optimism for new nuclear plant construction and operation in the U.S. is the significant increase in plant reliability and availability over the last 40 years.

This paper provides insights on how the nuclear industry worked to improve the capacity factor of nuclear plants and ultimately reduce the cost to operate nuclear power plants.

The Experimental Breeder Reactor No. 1 (EBR-I) in Arco, Idaho produced the world's first electricity from nuclear technology in December 1951. In the next two decades, nuclear power demonstration plants and test reactors were built and operated in the U.S. and worldwide to bring nuclear technology to commercial acceptance. This nuclear power technology development was supported by the successful construction of the large number of U.S. Navy ships, particularly submarines, using nuclear reactor propulsion.

By the late 1960s, large nuclear power plants were being ordered, constructed, and placed in operation by the U.S. electric utilities at an increasing rate. In the early 1970's, the nuclear industry in the U.S. was just beginning to develop experience in the operation of nuclear power plants. The early U.S. commercial nuclear power plants were, by 1972, the least expensive sources of electricity. By 1978, more than 200 large nuclear power units were operating, under construction, or were awaiting construction permits in the U.S..

Two significant events caused the waning of nuclear power in the U.S. in the early 1980's. The first significant event was the nuclear accident that occurred at TMI-2 in 1979 and the second significant event was the severe U.S. recession that began in 1981. These events along with new regulatory requirements as a result of the TMI-2 event caused the cost of building the nuclear reactors to increase dramatically. Instead of the cheapest form of electricity, nuclear became the highest priced electricity to produce. Therefore, numerous plants were cancelled and none were ordered for many years.

While the number of nuclear power plants in the United States has remained relatively constant for the past several decades, (the last nuclear reactor to begin commercial operation, Watts Barr, came online in 1996) the percentage of nuclear power in the national energy mix has increased, as shown in the Figure 1. A significant portion of the increase in nuclear generation was achieved by a substantial increase in the overall capacity factor of the U.S. plants from about 60% in 1980 to over 90% today. This large increase in capacity factor was accomplished by reducing outages, extending fuel cycles, using higher burnup fuel, reducing unplanned outages and fuel failures. This increase in capacity factor combined with increases in power in various plants (power uprates) this allowed nuclear power plants to maintain and increase their share of electricity generation. Such an increase in nuclear generation is the equivalent of having built 25-30 nuclear power plants during that period. Clearly such gains are no longer available as the capacity factors cannot increase much more and new nuclear base load capacity will be needed to maintain nuclear power percentage of electric generation. In addition, the ability to justify to the Nuclear Regulatory Commission (NRC) plant life extensions allows current plants to continue operation past their original planned life cycle, which lessens the need for new plant construction, but does not eliminate the critical requirement for new plant construction.

The following sections present the most notable ways that the efficiencies of nuclear power plants were improved over the last 30 years.

2.0 IMPROVING PLANNED AND UNPLANNED OUTAGES

The competitive environment for electricity generation has caused utilities to look for ways to improve power plant operation and maintenance requirements, including the efficient use of resources, efficient management of plant evolutions such as on-line maintenance, unplanned and planned outages.

Nuclear power plant outage management is a key factor for good, safe and economic nuclear power plant performance. Good outage management involves many aspects, which include utility administration, co-ordination of available resources, nuclear safety, regulatory and technical requirements and, all activities and work hazards, before and during the outage (Ref. 3). Plant outages (planned and unplanned) are shutdowns in which activities are carried out while the unit is disconnected from the electrical grid. The outage is the period where significant resources are spent at the plant, while replacement power must be purchased to meet the utility's supply obligations. Therefore, the outage has a significant impact on unit availability and net income for the utility. A planned outage is where the utility schedules an outage to replace fuel and support other maintenance activities. Typically, the utility has adequate time to plan resources and events during the outage to optimize outage execution to minimize cost and duration of the outage.

An unplanned outage is probably one of the worst situations for a utility where a plant outage occurs due to an unplanned scram or reactor trip of the reactor or due to some technical, safety or regulatory reason that the plant has to stop generating electrical power. The utility does not have much time to plan and resources have to be mobilized quickly. Usually the unplanned outage does not require the movement of fuel; therefore it is normally short in duration.

Over the last 30 years the utilities have spent significant resources on eliminating unplanned outages such as increasing scram reliability; identifying root causes of the unplanned events and fixing them; and training operators and maintenance in proper techniques to ensure reliable operation. Figure 2 shows the reduction of unplanned outages from about 9 to 3 events per year from the time period of 1976-1979 to 1986-91. This reduction in unplanned outages represents a significant improvement in the nuclear plant reliability, cost and safety of nuclear power plants.

Planned outage management is very complicated since it integrates the plant directives, the coordination of available resources, safety, regulatory and technical requirements and, all activities and work before and during the outage. Each plant develops its strategy for short term, middle term and long term outage planning. Extensive efforts are usually directed towards detailed and comprehensive preplanning to minimize outage duration, avoid outage extensions, ensure future safe and reliable plant operation and minimize personnel radiation exposures. Planning and preparation are important phases in the optimization of the outage duration which should ensure safe, timely and successful execution of all activities in the outage. The post outage review provides important feedback for the optimization of the next outage planning, preparation and execution.

The fundamental basis for outages during the lifetime of a nuclear power plant are strongly affected by plant design and layout. The choice of fuel cycle length, desired mode of operation, operational strategies, maintenance periods for the different components, requirements of the NRC and the electricity market affect the duration and frequency of outages.

In the medium and long term planning, it has become a good practice to categorize the outages in three or four types with the objective to minimize the total outage time. The outages may be categorized into four different kinds:

- Refueling only, which could be worked out in 7 to 10 days,
- Refueling and standard maintenance, which could be worked out in 2 to 3 weeks,
- Refueling and extended maintenance, which can last for one month,
- Specific outage for major back fittings or plant modernization which could take more than one month.

When the utility operates several nuclear power plants, a reference outage is defined as a generic outage including common activities to all outages. The reference outage could be, for instance, a refueling and standard maintenance outage. Since the utility has several plants, the standard outage process can be used by all of the plants as a basis for developing the outage plan for a particular plant. Additionally, outages can be planned not to coincide with other plants in the fleet, thereby allowing the plants to share resources. The use of a standard outage plan and shared resources can save the multi-plant utility significant money.

Outages can be optimized by different initiatives that can include the following:

- Ensure that all work that can be performed while on line is completed prior to the outage.

  Many U.S. Utilities have a modification group composed of individuals from operations, maintenance, schedule and planning, design and system engineering, reactor engineering, nuclear licensing, quality control and assurance and contracts, which develop modification priorities (usually set by operations and maintenance) that are implemented while the plant is still on-line. Working together in a highly functional team, the modification group has the clout to identify a modification that is needed to make the plant more reliable, ensure that the modification improves plant safety, ensure that necessary resources are provided, ensure necessary design engineering is performed in a timely manner, and that the modification is scheduled and planned in an optimum manner. By performing this work on-line, the utility not only improves reliability and safety of the plant in a timely manner, but also eliminates work that may be required during the outage, thereby shortening the length of the outage.

- Make sure that all maintenance activities that can be accomplished on-line are performed before the planned outage.

- Plan Plan Plan

  A successful outage always has a plan that was rehearsed and reviewed many times over. In the detailed planning and preparation, the following items should be considered:

  - ✓ Pre-outage milestones including planning, materials, schedule development, external services contracts, clearance preparation, As Low As Reasonably Achievable (ALARA) reviews, design issues, regulatory issues, etc.,
  - ✓ Outage duration for all 3 phases: shutdown, execution of work and startup,
  - ✓ Final scope of work/activities,
  - ✓ Outage schedule, including the main outage schedule and work and safety related schedules (separate schedules for systems, reactor, turbine, startup, etc.). Those schedules shall comply with the main outage schedule. For each activity in the critical path, a separate schedule should be created.
  - ✓ Work packages, including work orders and permits, instructions and procedures, materials, spare parts, consumables, human and material resources, special tools, post maintenance testing and startup programs, etc.

By implementing the strategies discussed above, utilities have shortened the outage time significantly from 1990 to 2000, as shown in Figure 3. After 2000, a plateau has been reached for outage duration since the fuel reload and required maintenance are generally of fixed length. Until fuel reload and required maintenance time durations can be shortened, the 33 to 40 day outage time plateau will remain.

Figure 3 shows the improvements in shortening the average outage in the U.S from 1980 through 2009.. This decline in outage length from an average of 106 days in 1991 to 38 days on 2008 represents a significant saving to the utilities and ultimately to the U.S. consumer.

3.0 FUEL COST IMPROVEMENTS AND IMPROVED FUEL RELIABILITY

3.1 Fuel Costs and Efficiencies

This is the total annual cost associated with the "burnup" of nuclear fuel resulting from the operation of the unit. This cost is based upon the amortized costs associated with the purchasing of uranium, conversion, enrichment, and fabrication services along with storage and shipment costs, and inventory (including interest) charges less any expected salvage value.

For a typical 1,000 MWe BWR or PWR, the approximate cost of fuel for one reload (replacing one third of the core) is about $40 million, based on an 18-month refueling cycle (Ref. 4). The average fuel cost at a nuclear power plant in 2009 was 0.57 cents / kWh.

Utilities have strived to achieve minimum fuel cost associated with reload fuel by soliciting several fuel vendors to bid on the fuel reload. During this process, the utility will also solicit special cost saving features such as power uprate services and extended plant analyses. By soliciting these services through the fuel bid, the utilities will typically get the best price for these services.

Because nuclear plants refuel every 18-24 months and the utility buys about 3 reloads at a time, they are not subject to fuel price volatility like natural gas and oil power plants.

There are a number of research projects that are exploring ways to improve fuel efficiency. In a three-year project completed recently for the U.S. Department of Energy, Hejzlar and Kazimi of MIT teamed up with Westinghouse and other companies to look at making a fuel for one kind of reactor, the pressurized water reactor (PWR), 30 percent more efficient while maintaining or improving safety margins.

They changed the shape of the fuel from solid cylinders to hollow tubes. This added surface area that allows water to flow inside and outside the pellets, increasing heat transfer.

Based on preliminary findings, the fuel may be easy to manufacture and capable of boosting the power output of PWR plants by 50 percent.

3.2 Operation & Maintenance (O&M) Costs

This is the annual cost associated with the operation, maintenance, administration, and support of a nuclear power plant. Included are costs related to labor, material & supplies, contractor services, licensing fees, and miscellaneous costs such as employee expenses and regulatory fees. The average non-fuel O&M cost for a nuclear power plant in 2009 was 1.46 cents / kWh.

3.3 Production Costs

Production costs are the O&M and fuel costs at a power plant. Since 2001, nuclear power plants have achieved the lowest production costs between coal, natural gas and oil (Ref. 4).

3.4 Fuel Failures

Fuel failures in operating nuclear power stations can lead to a power derate of the plant to protect the fuel from more failures, the shutdown of the plant due to too many fuel failures and in all cases higher radiation levels in the plant. The cost associated with the loss of power is obvious, but the higher radiation levels can lead to maintenance and operation issues that will cause higher cost for operation & maintenance and possibly a lower capacity factor for the unit.

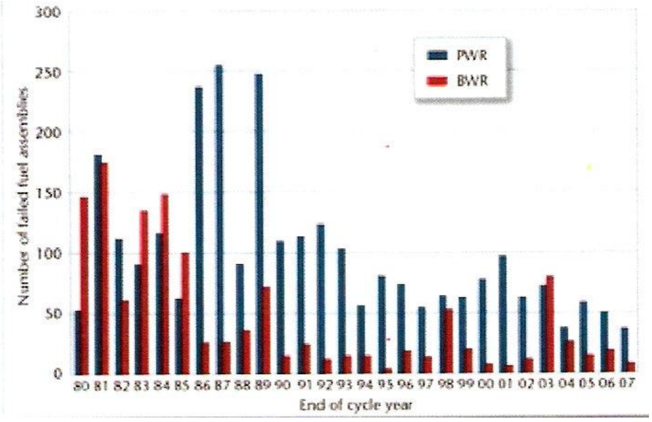
Fuel failures have been traced to several different causes including crud/corrosion, debris, grid fretting, PCI-SCC and unknown causes. The most common of these fuel failure causes are corrosion and crud, mechanical fretting wear (foreign material such as a piece of wire vibrating against the fuel rod surface), and pellet cladding interaction (PCI – stress buildup on the cladding due to contact with the fuel pellets and interaction with the aggressive radioactive environment on the inside of the fuel rod).

The total number of fuel failures, for both BWR and PWR plants combined, is significantly lower today than in past decades. However, while the industry has moved in the right direction, the number of fuel failures since 1990 has not markedly decreased (see Figure 4). This reduction in the number of fuel failures can be attributed to utilities being more conscientious about fuel failures and by the utilities applying. The Institute of Nuclear Power Operations (INPO) and the Electric Power Research Institute (EPRI) guidance in their day to day operational activities in the nuclear power plant.

In 2006, the INPO set an ambitious goal to achieve zero fuel failures by 2010. In response, U.S. nuclear owners and operators backed a fuel integrity initiative that emphasized the development of fuel reliability guidelines. In the first instance, INPO led the development of guidance documents summarizing current industry information to assist utilities in improving fuel integrity and performance. Continued emphasis on reducing fuel failures will pay a high dividend in the final cost evaluations of a nuclear power plant.

EPRI has developed a series of guidelines to help eliminate fuel failures at nuclear power plants, with the aim of achieving INPO's goal of zero fuel failures by 2010 (Ref. 5).

Figure 4 Number of U.S. Fuel Failures Since 1980



4.0 POWER UPRATE

The NRC regulates the maximum power level at which a commercial nuclear power plant may operate through the plants' license. This power level, along with other plant specific parameters, forms the basis for the specific analyses that demonstrate that the facility can operate safely. The maximum allowed reactor thermal power appears in the plant license, or technical specifications, and is commonly referred to as the Current Licensed Thermal Power (CLTP). Since this power level appears in the plant license, it can only be changed by a License Amendment Request (LAR) that must be approved by the NRC prior to implementation. This process of requesting operation at thermal power levels above the current licensed power level is referred to as a

Power Uprate. The notion of power uprate has been around since the late 1970's. In fact, the first power uprate applied for and granted by the NRC occurred at Calvert Cliffs in 1977 and 1978. Since then the NRC has reviewed and approved some 135 license amendments for operation at power above the original licensed thermal power (OLTP) (Ref. 6).

There are three types of power uprates, which are described below.

4.1 Measurement uncertainty recapture (MUR) power uprates

This increase in licensed power takes advantage of the requirement in 10CRF50 Appendix K that all safety analysis must be performed at 102% of licensed reactor power. The additional 2% in thermal power accounts for measurement uncertainty when calculating reactor power. Since the 2% requirement appears in 10CFR50 Appendix K, this uprate is sometimes referred to as an Appendix K uprate.

An MUR is accomplished by adding high precision feedwater flow measurement devices, which reduce the uncertainty in the feedwater flow measurement thereby allowing the plant to operate at a higher power level. Feedwater flow is used as a basis for reactor power in nearly all nuclear plants. An MUR always results in an uprate of less than 2% of thermal power, since it is impossible to eliminate all measurement imprecision, and it typically adds 1.5% to 1.7% of CLTP. Since the new power level is within the currently analyzed limits, it requires little or no reanalysis and no modifications to nuclear safety systems. Also, because of the relatively minor change in power, an MUR is usually well within the capabilities of the Balance Of Plant (BOP) systems and requires little or no changes to those systems. Therefore, it is usually accomplished for a relatively small effort and reasonable cost.

4.2 Stretch power uprates

The second type of power uprate is referred to as the stretch power uprate. Stretch uprates are typically 5% to 7% of CLTP. Stretch uprates take advantage of the margin that is inherent in the design and construction of most power plants. Typically, a stretch uprate was selected at a level where no changes were required to the plant nuclear safety systems and minimal changes, if any, were required for the BOP side. This made the stretch uprate relatively easy and inexpensive to implement. Since the power level is higher than an MUR, the system evaluation required for a stretch uprate is more complex.

A large percentage of the early power uprate requests were stretch uprates. There are currently no requests for stretch uprates on the docket and very few expected requests for stretch uprates. The desire for additional nuclear power capacity has replaced the stretch uprates with the last and more aggressive form of power uprate, the extended power uprates. In fact, several plants that already operate at stretch levels are pursuing or have been granted extended uprates. This is due to the favorable cost benefit for increased power at these facilities.

4.3 Extended power uprates (EPU)

Extended power uprates are typically greater than stretch power uprates and have been approved for increases as high as 20 percent of the OLTP. These uprates may still be within the original design limitations of the nuclear safety systems and require little or no modification to those systems, but in most cases there is typically a large amount of reanalysis required for these uprates and the engineering effort to support the EPU can be formidable.

Since the power output after an EPU is substantially higher, they are typically accomplished with major modifications to the BOP systems. For example, a new High Pressure turbine is required to support EPU. Extended power uprates typically also require major changes to condensate, feedwater, feedwater heaters, and electrical generation systems. These modifications make extended power uprate projects large and difficult to manage. Project costs can normally run in the hundreds of million dollars. However, even at these large project costs, they still deliver more kilowatts per dollar than new build of similar power levels.

Each utility evaluates the potential for a power uprate based on the total local economic environment in its sales territory. The potential for increased revenue is balanced by the cost of the uprate and an economic decision is reached based on the project's return on investment (ROI). In most instances, the ROI for a power uprate is favorable even in the current economic downturn. This is particularly true in the case of large EPUs. For example, a 20% EPU at a 1,000 MWe power plant results in a 200 MWe gain. Even at project costs that approach $500 Million, a $2,500 per KW cost is still acceptable when compared to new build for fossil plants. When incremental fuel costs and cost stability are accounted for, nuclear power uprates have an economic and environmental advantage.

Utilities perform detailed cost/benefit analyses to ascertain the best power uprate category to pursue for their particular regulatory and financial situation. The NRC has approved 135 power uprate applications to date (Ref. 7).

The cumulative additional electric power from all power uprates approved since 1977 is about 5,700 megawatts, which is the equivalent of more than five large new reactors added to the grid. The NRC currently has 16 power uprate applications under review, comprising a total of about 1,145 megawatts of electric power. The NRC expects to receive 39 new power uprate applications in the next five years for a total of about 2,400 megawatts of additional electric power output (Ref. 7).

Uprating nuclear units is costly and technically challenging but it has been proven that owners can potentially receive a significant ROI with their uprate projects. Even so, the industry is looking for ways to reduce costs and project time without compromising quality and safety. Careful planning and common sense strategies must be put in place by all involved in uprate projects and to do that, many challenges must be faced (Ref. 8).

5.0 PLANT LIFE EXTENSION

The NRC is the government agency established in 1974 to be responsible for regulation of the nuclear industry, notably reactors, fuel cycle facilities, materials and wastes (as well as other civil uses of nuclear materials) (Ref.9).

In an historic move, the NRC in March 2000 renewed the operating licenses of the two-unit Calvert Cliffs nuclear power plant for an additional 20 years. The applications to NRC and procedures for such renewals, with public meetings and thorough safety review, are exhaustive. The original 40-year licenses for the 1970s plants were due to expire before 2020, and the 20-year extension to these dates means that major refurbishing, such as replacement of steam generators, can be justified.

As of the end of 2009 the NRC had extended the licenses of 59 reactors, over half of the U.S. total. The NRC is considering license renewal applications for further units, with more applications expected by 2013. In all, about 90 reactors are likely to have 60-year lifetimes, with owners undertaking major capital works to upgrade them at around 30-40 years of age.

Extended lifetime from 40 to 60 years will add 20 years of operational abilities for all of these power plants at an additional cost that is small compared to building new plants. This represents a significant savings to the U.S. consumer.

6.0 IMPROVED NRC OVERSIGHT AND UTILITY MAINTENANCE AND SURVEILLANCE PROCEDURES AND PROCESSES

The NRC has a new oversight and assessment process for nuclear plants. Having defined what is needed to ensure safety, the NRC now has a better-structured process to achieve it, replacing complex and onerous procedures which had little bearing on safety. The new approach yields publicly-accessible information on the performance of plants in 19 key areas (14 indicators on plant safety, two on radiation safety and three on security). Performance against each indicator is reported quarterly on the NRC web site according to whether it is normal, attracting regulatory oversight, provoking regulatory action, or unacceptable (in which case the plant would probably be shut down). These new processes help the NRC manage the nuclear utility industry more effectively, which helps the utilities be more efficient.

On the industry side, the Institute of INPO was formed after the Three Mile Island accident in 1979. A number of U.S. industry leaders recognized that the industry must do a better job of policing itself to ensure that such an event should never happen again. INPO was formed to establish standards of performance (Ref. 10) against which individual plants could be regularly measured. An inspection of each member plant is typically performed every 18 to 24 months.

It is difficult to quantify the amount of improved reliability that these improved procedures and processes have provided, but the improved understanding for the operation and maintenance staff of the plant has been enormous.

7.0 CONCLUSIONS

The increase in nuclear generation has been achieved by a substantial increase in the overall capacity factor of the U.S. plants from about 60% in 1980 to over 90% today. This large increase in capacity factor was achieved by reducing outage durations, extending fuel cycles, using higher burnup fuel, and by reducing unplanned outages and fuel failures. Combined with increases in power in various plants (power uprates), allowed the nuclear power option to maintain and increase its share of electricity generation. Such an increase in nuclear generation is the equivalent of having built 25-30 nuclear power plants during that period.

The reduced length of the planned outages from 106 days for an average operating plant in 1991 to 38 days in 2008 and the reduced number of unplanned outages improved plant availability and cost. The reduction in planned outage length and the number of unplanned outages represents a significant improvement in the nuclear plant availability, cost and safety of nuclear power plants.

Additionally, power uprate, which allows plants to operate at a higher power, and power plant life extension, which extended the operating life of a power plant beyond 40 years allowed more electrical power to be generated at a reduce total production cost and construction cost, respectively. Also, fuel performance has improved to a very high level over the last 20-30 years.

These initiatives improved the overall performance of nuclear power in the U.S. and has provided adequate justifications to building more reactors in the U.S..

8.0 REFERENCES

1. "Learning by Accident? Reductions in the Risk of Unplanned Outages in the U.S. Nuclear Power Plants After Three Mile Island", Journal of Risks and Uncertainty, 13-175-198, (1996).

2. NEI; http://www.nei.org/resourcesandstats/documentlibrary/reliableandaffordableenergy/graphicsandcharts/refuelingoutagedays/
3. IAEA-TECDOC-1315, "Nuclear power plant outage optimisation strategy", October 2002
4. NEI; http://www.nei.org/resourcesandstats/nuclear_statistics/costs
5. EPRI; http://www.neimagazine.com/story.asp?sc=2050914
6. NRC Power uprate applications. http://www.nrc.gov/reactors/operating/licensing/power-uprates/status-power-apps/approved-applications.html
7. SECY-10-0070, May 20, 2010
8. The Nuclear Power Uprate Conference, http://www.nuclearenergyinsider.com/nuclear-power-uprate-conference/
9. WNA, World Nuclear Association, http://www.world-nuclear.org/info/inf41.html.
10. "Guidelines for the Conduct of Maintenance at Nuclear Power Stations", INPO Guideline 97-013, December 1997.