WNA Report

Optimized Capacity: Global Trends and Issues

A Report by the World Nuclear Association's
Capacity Optimization Working Group

World
Nuclear
Association

Contents

3. Industry Trends

6. Definitions

Figures

Executive Summary

This paper reflects the research of the World Nuclear Association's Capacity Optimization Working Group; a group constituted to identify means by which nuclear operators worldwide can both determine and attain their optimal capacity. In order to progress towards this goal, this report establishes a status baseline and undertakes high-level analysis to understand at what point the global industry currently stands and what the dominant issues in utilization of the installed power base of the current nuclear fleet are.

The electrical output of a nuclear power plant is dependent on a wide variety of factors. Issues as diverse as engineering, organization, regulation and finances all impact on the ability of the plant to produce electricity. Within the boundaries set by these 'real world' issues it is desirable that a nuclear reactor should perform at its best achievable capacity, its optimized capacity. Additionally, the boundaries themselves can also be questioned, understood and influenced.

In the 20-year period from 1980 there was a significant rise in the median global actual energy utilization of reactors' maximum power capability[1] from 68%, culminating in 2002 in a historical maximum of 86%[2]. However, since around the turn of the century this growth has levelled off and has remained constant at around the 85% mark for the last 8 years, which suggests that renewed focus should be placed on more effective utilization of the existing nuclear fleet.

In 2008 the global median capacity factor was 84.5%, but there was a very broad spread in this performance indicator between individual plants. Generally, this variance is not explained by the reactor type used, or by age of the reactor. Indeed, the best performing utilities represent a range of technologies, vendors and regions, suggesting that performance is independent of these choices.

Globally speaking, in recent years 94% of a plant's unavailable capacity is due to reasons under management control, the dominant cause being maintenance combined with refuelling. Best performing utilities have significantly shorter and better-controlled outages that are of at least as good quality. More broadly than this, best performers maximize their availability and minimize their unplanned unavailability; they plan for success and are able to stick with their plan.

It is seen that the major direct cause of unplanned loss is failure or problem with plant equipment, with the turbine and auxiliary system having the greatest effect. Additionally we see that indicators of plant safety and capacity are linked: a well-managed plant is generally both productive and safe.

With potential significant benefits in safety, economics, security and environmental performance available, it is clear that further work on optimizing the current global nuclear fleet's capacity has merit. In particular, the Capacity Optimization Working Group has identified four key areas for development:

- Root cause analysis applied to unplanned energy loss
- Case studies in managing planned energy loss
- More detailed investigation of ageing
- Development of a mathematical model of optimal capacity

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[1] Under ambient conditions.

[2] This performance indicator is known as the capacity factor.

1 Introduction

The electrical output of a nuclear power plant is dependent on a wide variety of factors. Issues as diverse as engineering, organization, regulation and finances all impact on the ability of the plant to produce electricity. In 2008 these factors contributed to a spread of production between 0%[3] and over 100%[4] of the reactor's maximum power capability[5]. Within the boundaries set by these 'real world' issues it is desirable that a nuclear reactor should perform at its best achievable capacity, its optimized capacity. Additionally, the boundaries themselves can also be questioned, understood and influenced.

The benefits of moving towards the attainment of optimized capacity are numerous and include:

- Safety – enhancing nuclear and industrial health and safety through minimizing unplanned outages and reducing associated transients
- Economic – maximizing the return on an asset-based business
- Security – contributing to the security and diversity of energy supply
- Environmental – increasing power generation from non-greenhouse gas emitting power and making best use of available materials and resources.

In 2008 the median capacity factor[6] for all the world's operating nuclear reactors was 84.5%; if this could be increased (in relative terms) by 10%, to a capacity factor of 93%, this would:

- Result in the production of an extra 260TWh, enough to power over 54 million homes[7]
- Be equivalent to connecting numerous[8] new reactors to the grid
- Avoid the emission of 260 million tonnes of carbon dioxide[9].

The capacity of the nuclear fleet should therefore be of interest to a wide audience including operators, financiers, policy makers and regulators, as well as the general public.

This paper reflects the research and collective experience of the WNA's Capacity Optimization Working Group, a group constituted to identify means by which nuclear operators worldwide can both determine and attain their optimal capacity. This paper is intended as a broad overview of the global trends and identifies the topics that will be covered in greater depth in subsequent reports.

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[3] Percentages quoted are the 2008 annual median capacity factor.

[4] A reactor can achieve over 100% by performing above its reference energy generation, generally through experiencing ambient conditions significantly different from its reference ambient conditions.

[5] Under ambient conditions.

[6] The capacity factor is a performance indicator which reflects the actual energy utilization of the unit for electricity and heat production.

[7] Based on the average energy consumption of a UK home.

[8] Approximately 35 1GW reactors.

[9] Estimated if coal had been used as a direct replacement.

2 Data Model

Data is required in order to evaluate the performance of a nuclear power plant, or groups of plants. A model is used to determine what data is useful to collect and to categorize it in an agreed standardized manner. Figure 1 shows the model that has been adopted for data values collected from nuclear power plants.

The reference unit power[10] is the maximum power capability of a unit under average ambient conditions. As shown in Figure 1, it can be split into two components, 'available capacity' and 'unavailable capacity'. The balance between these two components is determined by eight factors: outage execution, equipment reliability, regulatory environment, organizational factors, engineering, safety performance, finances, supply chain processes. These factors are expanded on in Section 4 of this paper.

Further, 'available capacity' can be broken down into what is and what is not supplied to the grid. Similarly 'unavailable capacity' can be broken down into elements that are or are not under plant management control. Finding and achieving the optimal balance between 'generation supplied' and the other three components at this level is the essence of WNA's work on capacity optimization.

Two additional important concepts can be defined using this model: 'availability' is the sum of the 'generation supplied' and 'available but not supplied'; 'capability' is the sum of the 'generation supplied' and 'available but not supplied' and the element of unavailable capacity which is 'not under plant management control'.

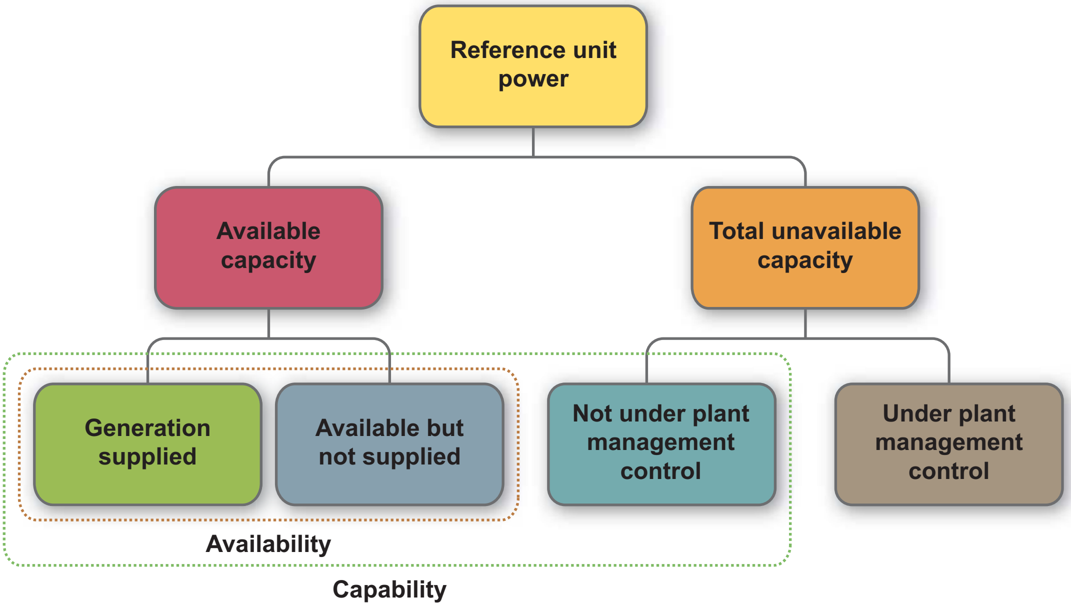

Figure 1: Data Model

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[10] The reference unit power is the maximum (electrical) power of the unit under reference ambient conditions. The reference power is based on design values, adjusted for reference ambient conditions. The reference unit power is expected to remain constant unless design changes that affect the capacity are made to the unit.

In order to determine performance measures, the concept of reference energy generation (REG) is used. It is determined by multiplying the reference unit power by the reference period[11]. By dividing the components at the lowest level of Figure 1 by REG, we derive a set of indicators that can be used across the nuclear fleet. The relationship between values and indicators is shown in Figure 2.

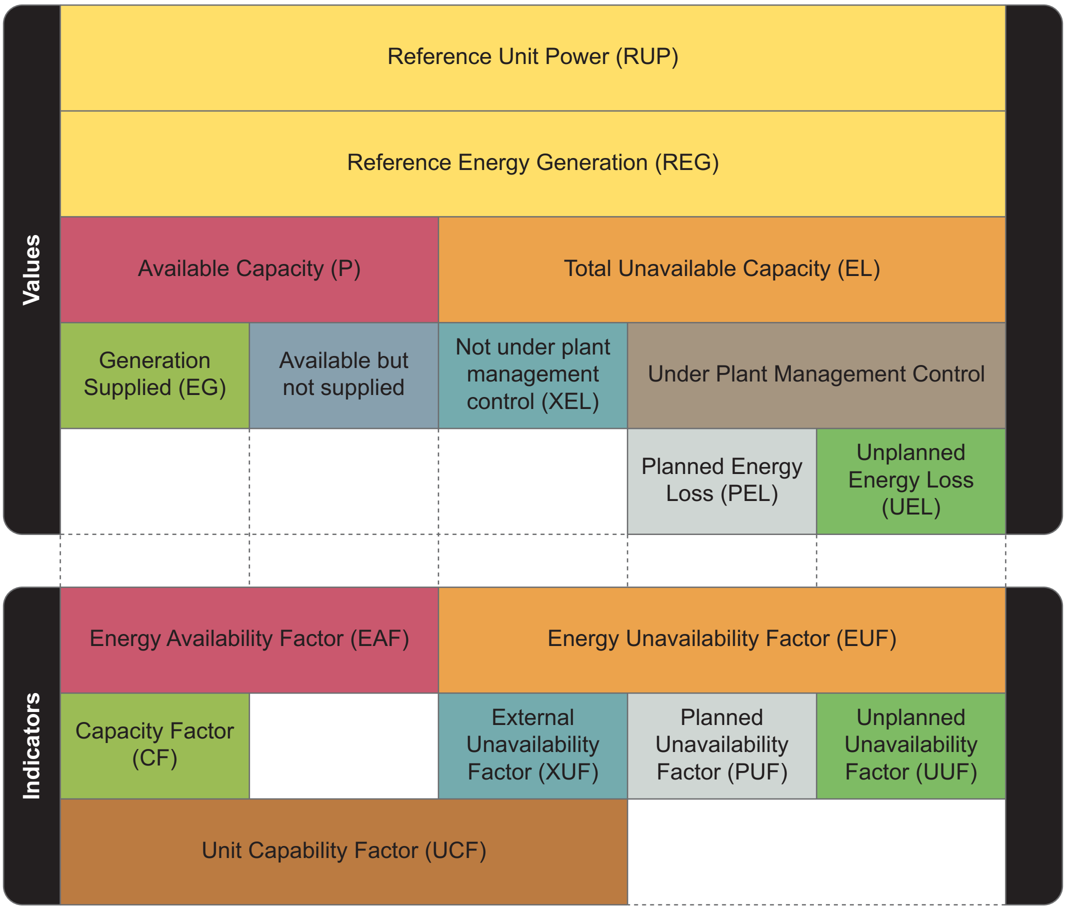

Figure 2: Performance Indicator Derivation

Performance indicators allow for meaningful statistical analysis of current and historic data held on the nuclear fleet. Of particular interest is the 'capacity factor' indicator that relates to the 'generation supplied' as discussed above. This indicator reflects the actual energy utilization of the unit for electricity and heat production.

More detailed definitions of these performance values and indicators can be found in Section 6 of this document.

Note: The data model, performance indicators and data used in this document are drawn from figures held in the International Atomic Energy Agency (IAEA) Power Reactor Information System (PRIS) which constitutes the most complete and authoritative technical data bank on nuclear power reactors in the world. This is with the exception of the capacity factor as defined here, which the IAEA refers to as 'load factor'.

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[11] The reference period is the time (in hours) over which the indicator is calculated.

3 Industry Trends

3.1 GLOBAL OVERVIEW

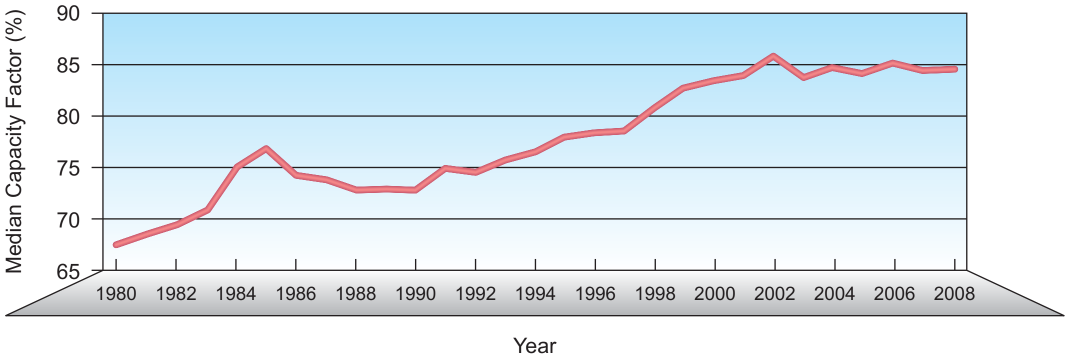


Figure 3: Global Capacity Factor over Time

Figure 3 shows that in the 20-year period 1980-2000 there was almost a 20% rise in the global capacity factor (CF) culminating in 2002 in a historical maximum of 86%. However, since around the turn of the century this growth has levelled off and has remained constant at around the 85% mark for the last 8 years. This trend suggests that renewed focus should be put on a more effective utilization of installed capacity base.

The 20% rise in the period 1980-2000 was despite an 8 year 'recovery' in the CF following the Chernobyl accident in 1986. There have been some specific cases that have affected progress more recently:

- TEPCO case in 2003 – long-term shutdown of 17 TEPCO units (2003 and 2004)
- Earthquake at Kashiwazaki Kariwa in July 2007 – 7 reactors not operated from this date
- Long-term shutdown in 2008 of Brunsbuettel and Kruemmel in Germany
- Ageing of Nuclear Power Plants (NPPs) – extended reconstructions of several old reactor units (for example, in 2008 eight reactors were not operated for this reason).

These cases are included in Figure 4. While the number of not-operated reactors is following an upward trend, their numbers are still low compared to the total number of operating reactors. Therefore these specific cases are perturbations in a general trend of levelling off, not the cause of the trend.

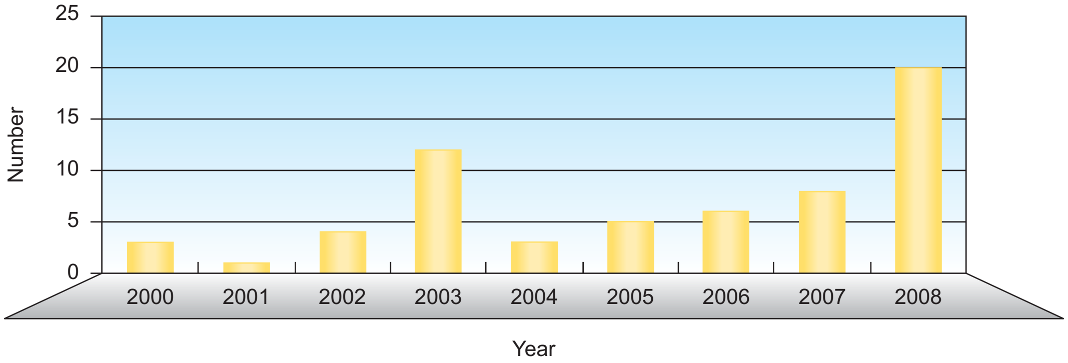


Figure 4: Number of Reactors Not Operated for the Entire Year

While Figure 3 shows a global median average CF, the actual CF of individual plants varies and in some cases varies very widely from the worldwide average as demonstrated in Figures 5 and 6. The fact there are differences, the causes of which are not necessarily understood, is the basis for the WNA's Capacity Optimization Working Group's work. The first step to improvement is understanding the differences.

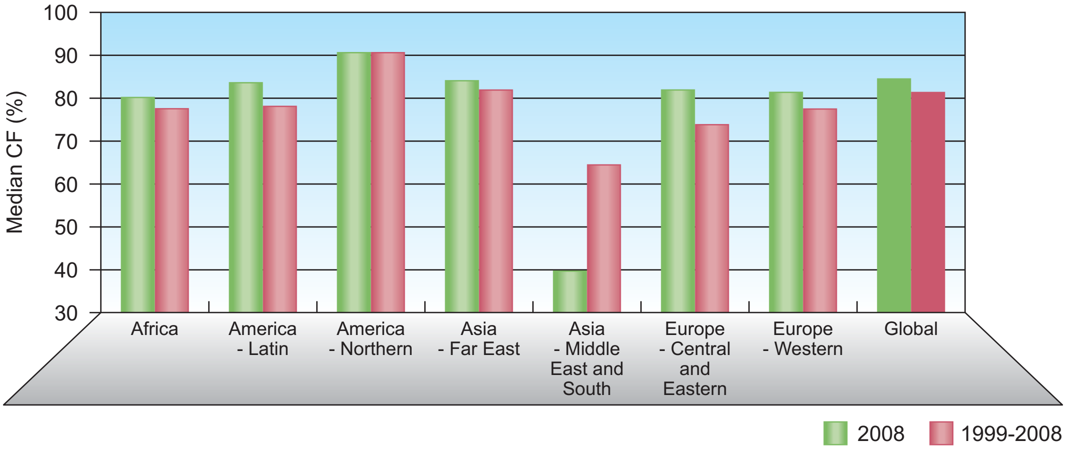


Figure 5: Long and Short Term Capacity Factors by Region

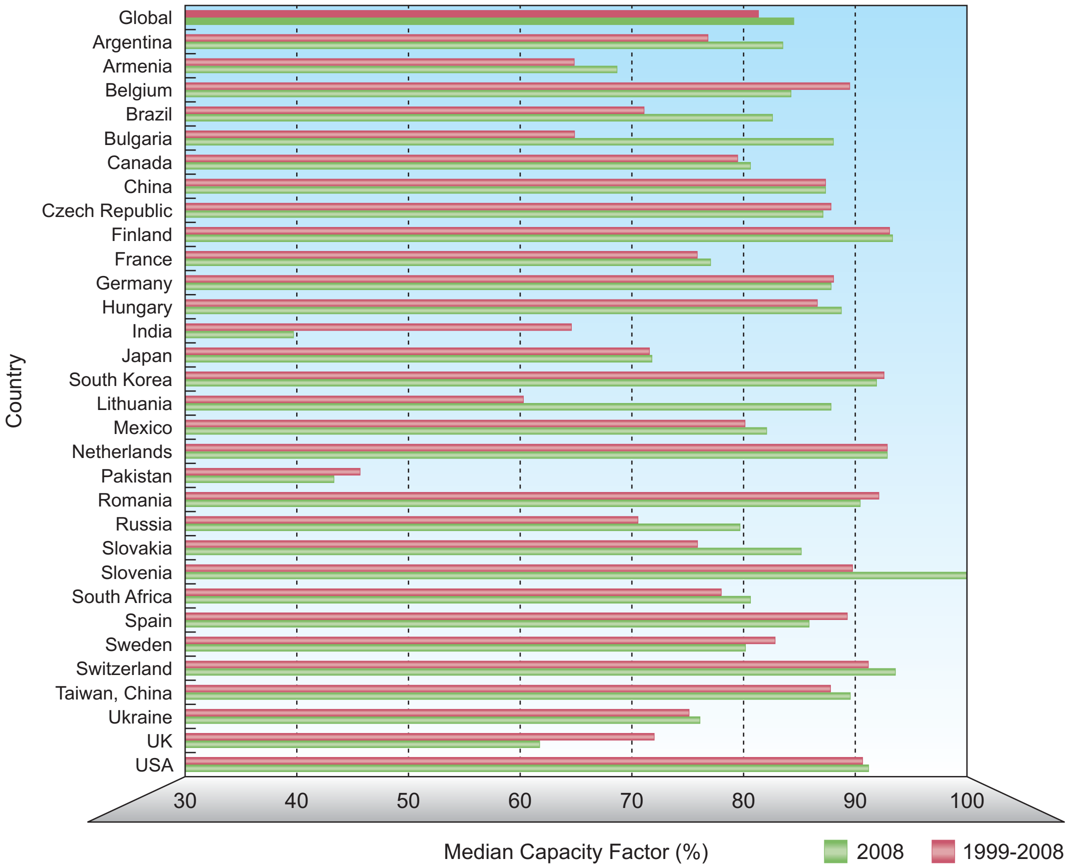
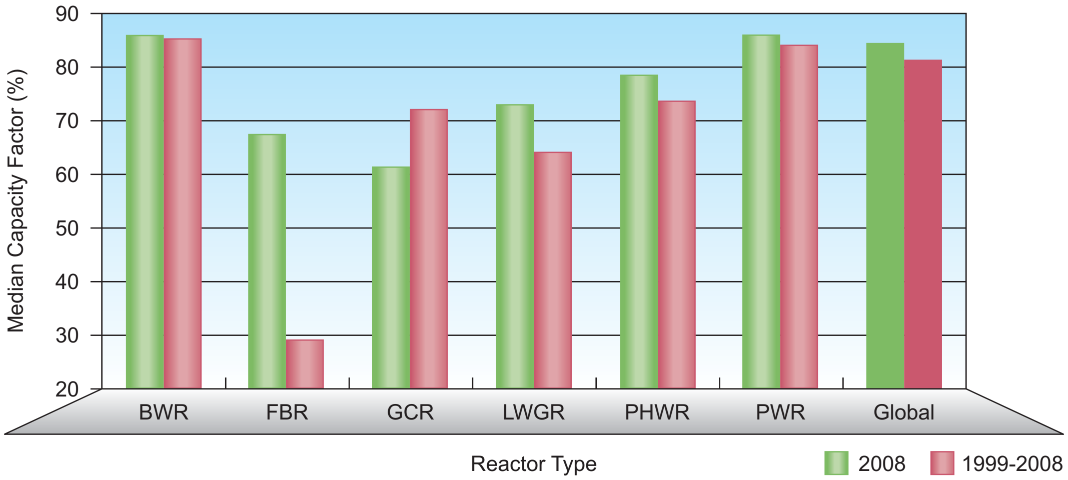


Figure 6: Long and Short Term Capacity Factors by Country

Figures 5 and 6 have been included to demonstrate the variation from the global average. There is a wide spread of CFs between regions and between countries within the same region. Local conditions can be seen to come into play more directly (for example fuel supply issues, seasonal demand variations, load following). While regions and countries may have restraints imposed on them by their local conditions, all can look to continuously improve performance within these boundaries.

Countries and regions will always be an important common denominator due to national and regional regulatory control. However, companies and workforces are becoming increasingly internationalized over time. If this trend towards globalization continues in the nuclear industry it will reduce the importance of reactor nationality.



BWR – Boiling Water Reactor (including ABWR)
FBR – Fast Breeder Reactor[12]
GCR – Gas Cooled Reactor (including AGR)
LWGR – Light Water Graphite Reactor (including RMBK)
PHWR – Pressurized Heavy Water Reactor (otherwise known as CANDU)
PWR – Pressurized Water Reactor (including VVER)

Figure 7: Long and Short Term Capacity Factors by Reactor Type

The PWR and BWR together account for over 80% of operating units. Figure 7 shows that there is effectively no difference between their global CFs over time. This similarity exists between two profoundly different reactor types. The ageing mechanisms, chemistry performance, and standard equipment are very different between these technologies, as are the operations, especially with respect to refuelling requirements. Yet, despite these differences, both technology types achieve similar performance, suggesting that technology is not a limiting factor to sustainable and efficient operation. The next most prevalent reactor is the PHWR, followed by the GCR and LWGR. Only two FBRs operate today and therefore they have been excluded from the statistical analysis in this paper[12].

The high availability of PWR, PHWR and BWR reactors is despite decreased performance of BWR and PHWR reactors in the last few years. The availability of BWR units has been significantly affected by the TEPCO case in 2003 and the earthquake in Japan in 2007 (all TEPCO units are of BWR or ABWR type). Had these technologies been operating at, or near, maximum practical capacity factor, the recent events would have resulted in a downturn in performance. This suggests that there is a strong reserve margin of capacity to be realized through operational best practices.

LWGR reactors have increased their availability significantly over the last few years. Performance of GCRs has decreased significantly mainly due to type-specific ageing plant issues. These decreases in performance may be attributed to end-of-life performance issues related to these technologies, as opposed to operational issues.

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[12] There are only two FBRs operating in the world and therefore they are not statistically significant but are retained in Figure 7 for completeness.

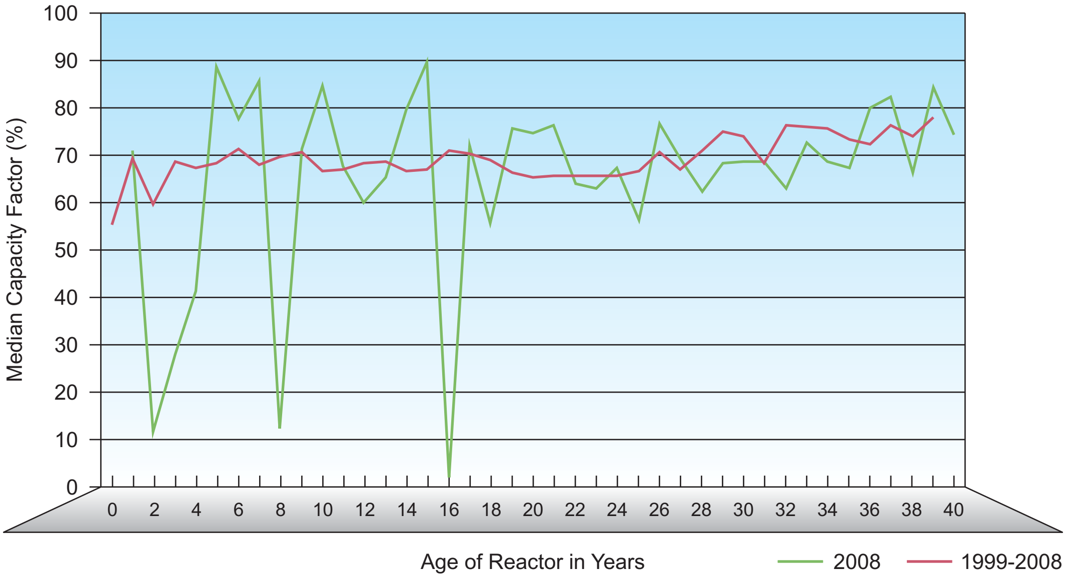

Figure 8: Long and Short Term Capacity Factors by Reactor Age

In general, no significant global age-related trend in capacity factor can be detected from Figure 8. This is good news for older plants, which can maintain historic output levels, and also for new plants, which do not appear to require any 'run-in' time, suggesting that industrial good practice in operations is being passed on.

Figure 4 shows an increase in the number of reactors off line for an entire year – it is believed that this is caused by increasing numbers of ageing reactors coming off line for major items to be refurbished. Therefore there are some ageing effects on the fleet which are being managed. But Figure 8 suggests that ageing reactors that are on-line are operating as well as new reactors.

What cannot be seen here is the cost of keeping older plants performing at historic levels, and whether this cost is comparable with the cost of operating younger plants. It is also important to remember that capacity factor here is different from output – older plants tend to have significantly lower reference unit power.

While Figure 8 gives an overview, it is suspected that there will be trends hidden within it. A further, more detailed analysis of ageing requires investigation by reactor type and reactor model. It also requires filtering to manage those cases when the capacity factor is affected by a non-ageing reason, such as an earthquake.

3.2 UNAVAILABLE CAPACITY

As shown in Figures 1 and 2, the power of a unit can be split into two parts; the Available Capacity (P) and the Total Unavailable Capacity (EL). EL can be further broken down into three components:

PEL – planned energy loss
UEL – unplanned energy loss
XEL – loss that is not under plant management control (external loss)

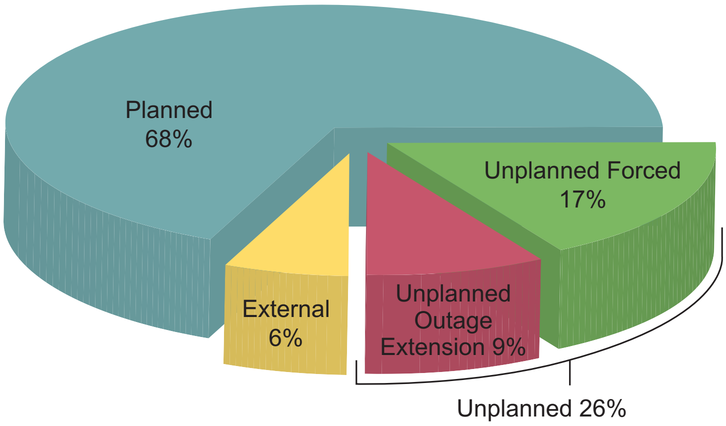

Figure 9: Energy Loss Distribution (2004-2008)

Figure 9 shows that globally, 94% of unavailable capacity is within plant management control.

Planned losses are the most significant factor, followed by unplanned losses. External reasons, which are not under plant management control, are the smallest cause. In Figure 9 unplanned losses (which are under plant management control) have been split into two components, demonstrating the importance of unplanned outage extensions. Clearly planned losses are important, but unplanned causes should also be addressed.

	Capacity Factor	Planned Unavailability Factor	Unplanned Unavailability Factor	External Unavailability Factor	Forced Loss Rate
TOTALS:	**82.79**	**10.34**	**2.49**	**0.36**	**1.42**
BWR	85.60	7.97	2.66	0.14	1.05
GCR	66.27	11.94	16.45	0.05	12.89
LWGR	71.43	20.21	1.14	1.67	1.05
PHWR	75.56	9.22	4.45	0.76	3.43
PWR	85.06	10.35	1.78	0.36	1.17

Figure 10: Median Performance Indicator by Reactor Type (2004-2008)

	Capacity Factor	Planned Unavailability Factor	Unplanned Unavailability Factor	External Unavailability Factor	Forced Loss Rate
TOTALS:	**90.30**	**7.08**	**0.79**	**0.00**	**0.43**
BWR	91.87	5.17	0.79	0.00	0.36
GCR	77.37	9.92	10.44	0.00	8.03
LWGR	78.16	17.29	0.27	1.15	0.05
PHWR	88.91	5.38	2.30	0.15	1.61
PWR	91.06	7.71	0.65	0.00	0.38

Figure 11: Best Quartile Performance Indicator by Reactor Type (2004-2008)

Demonstrated again in Figures 10 and 11 is that planned losses are most significant for all reactor types, except in the case of GCRs, where unplanned losses are most significant. Forced loss rate (FLR) is also significantly higher for this reactor type.

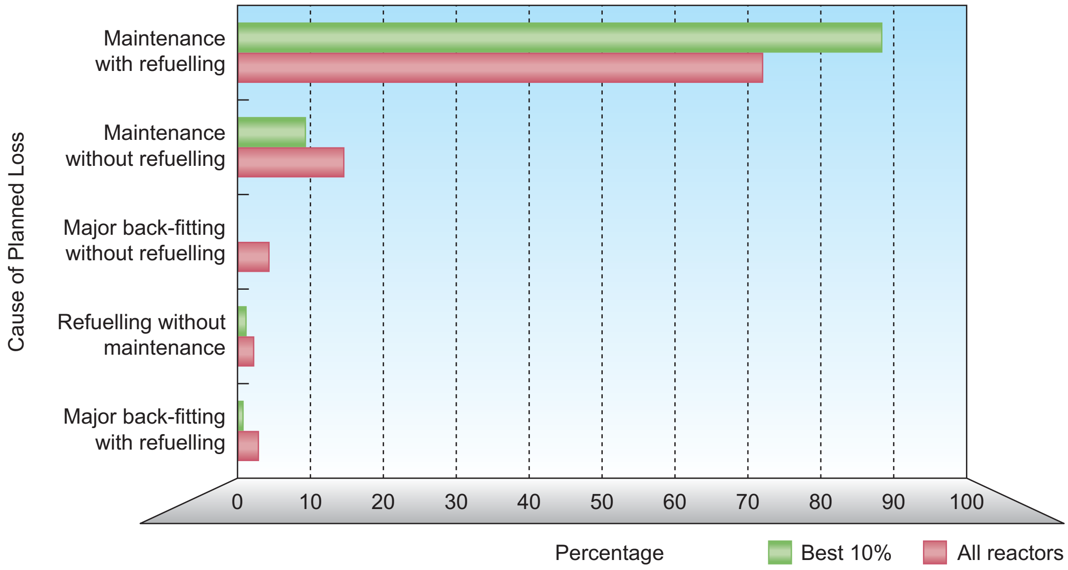

Figure 12: Planned Energy Loss Causes (2004-2008)

Figure 12 looks at planned loss in more detail. It can be seen clearly that a combined maintenance and refuelling outage is the dominant cause, accounting for approximately 72% of this loss category.

Looking at the best performing 10% of reactors in Figure 12 we can see this trend is exaggerated further. In best performers a combined maintenance and refuelling outage accounts for close to 89% of planned loss. Clearly both refuelling and maintenance are essential activities in nuclear power plant operations and the best performers will parallel plan these to make best use of any outage. Additionally, this data suggests that shorter outages do not result in increased losses in other categories, suggesting that the quality of the shorter outages is as good, if not better, than that of longer outages.

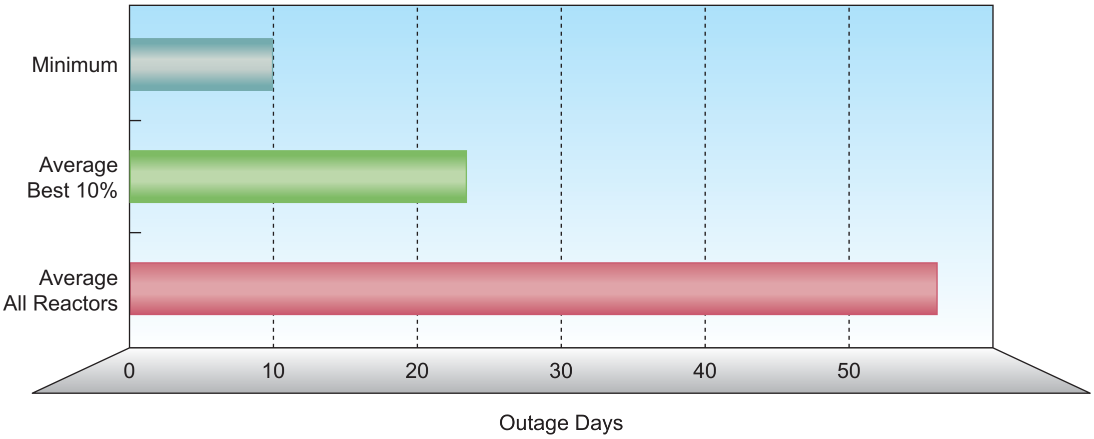

Figure 13: Refuelling Outage Durations (2008)

We can see in Figure 13 that not only do the best 10% of performers use outages to perform refuelling and maintenance but they also have less than half the average outage duration. Clearly a short refuelling duration is a key feature of best performance.

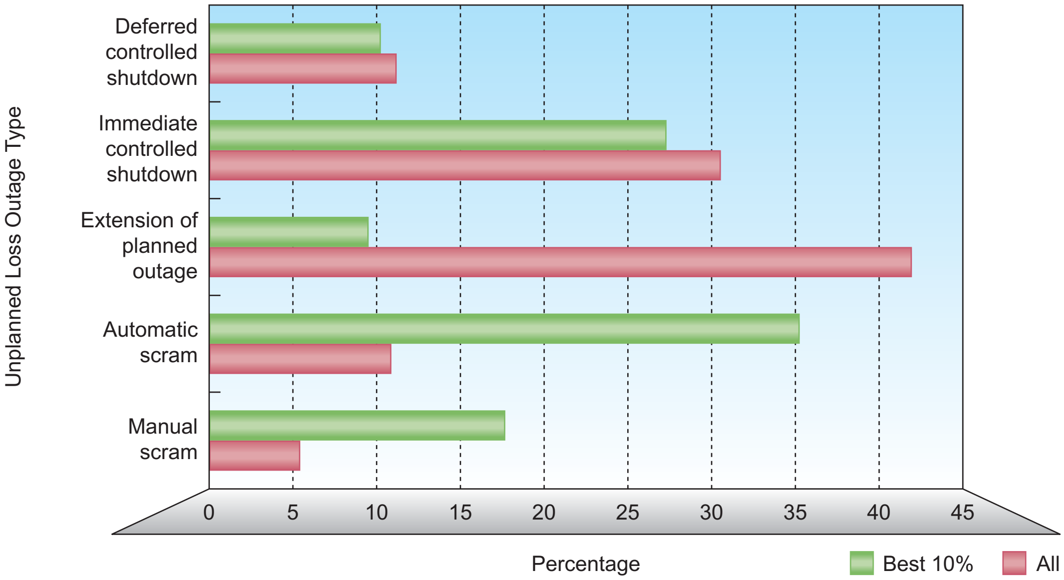

Figure 14: Unplanned Energy Loss by Outage Type (2006-2008)

Figure 14 looks at unplanned losses. It is immediately clear that for 'All' reactors, extension of planned outages is the primary mechanism, followed by controlled shutdowns and then scrams. In stark contrast, extension of planned outages is the weakest mechanism for best performers unplanned loss. Controlling the duration of an outage is a key feature of best performance in addition to a short refuelling duration.

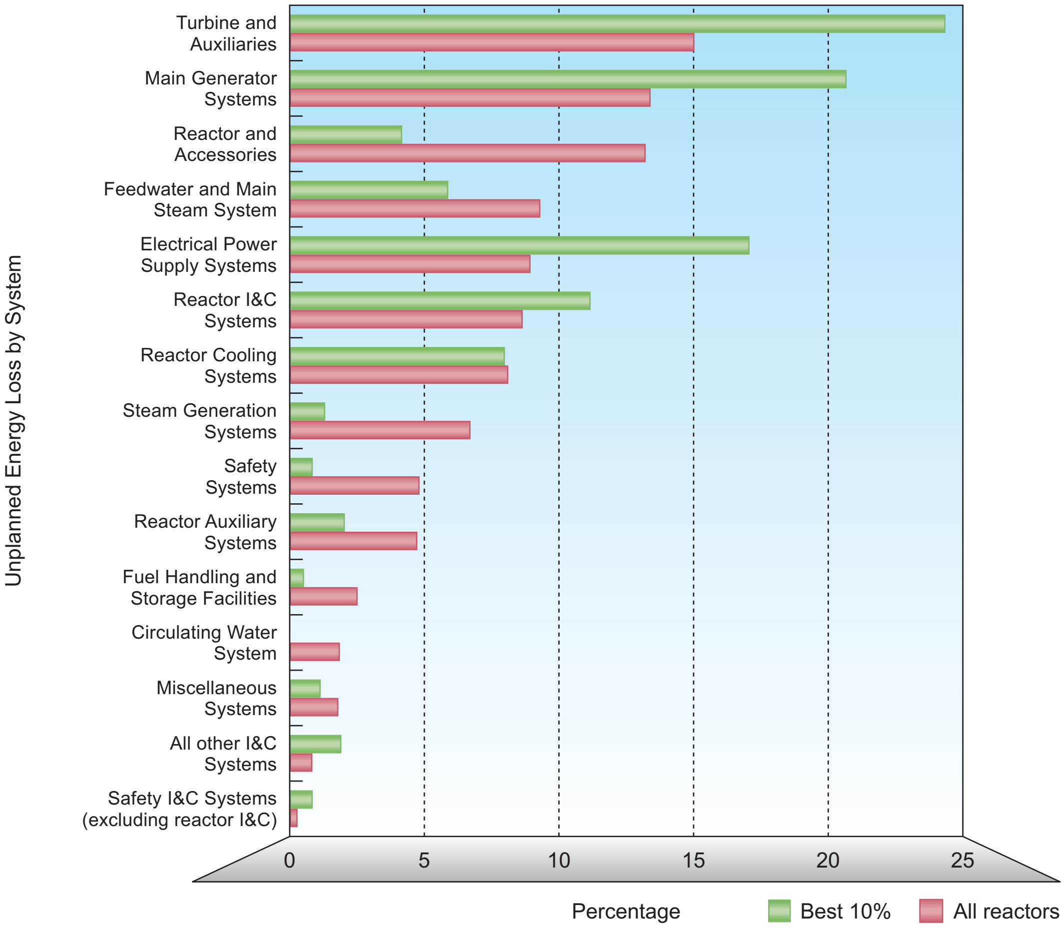

Figure 15: Unplanned Energy Loss by System (2004-2008)

Figure 15 shows the causes of unplanned energy loss by system.

The distribution of systems directly involved in unplanned energy losses for best performers is markedly different from that of for all reactors. For both groups, turbine and auxiliary systems are the biggest contributor to loss, followed by main generator systems. Best performers do significantly better in the category of reactor and accessories and also better in feedwater and main steam system, but less well in electrical power supply systems.

Not enough detailed data exists to perform an adequate analysis of what is driving the problems within each of these systems – either for all reactors or the best performers. Good quality equipment/component failure data to identify common causes and therefore prevent them would be of benefit to the industry. The sharing of root cause analysis information on equipment and system failures could result in global gains.

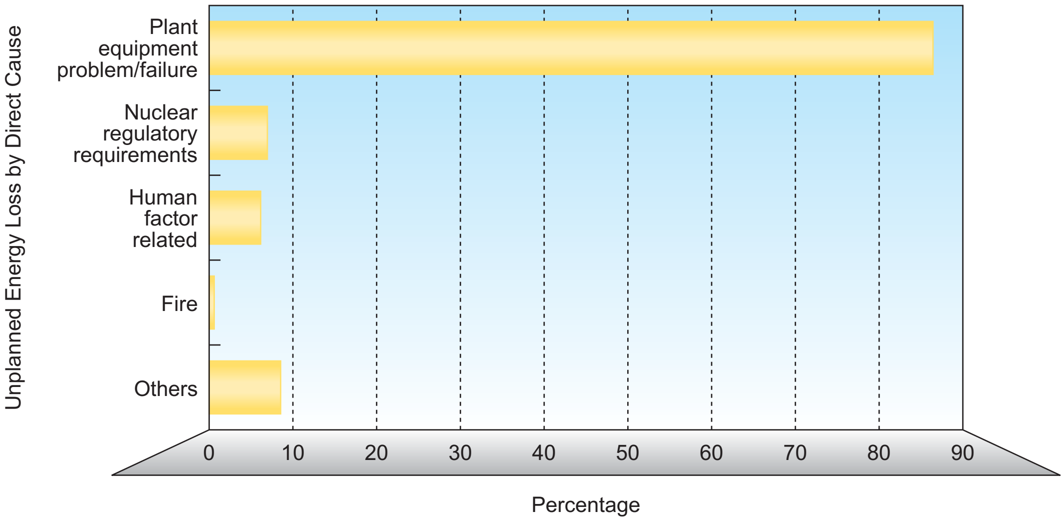

Figure 16: Unplanned Energy Loss by Direct Cause (2004-2008)

Figure 16 shows that the direct cause of unplanned energy loss is overwhelmingly attributable to equipment problems and failure. As with the systems analysis in Figure 15, not enough detailed data is available to analyse this further. Additionally, while direct cause is the immediate initiator for the unplanned loss and therefore understanding this is important, it is of limited value compared to understanding root cause, which is the initiating cause in the chain of events leading to the unplanned loss. It is suspected that root cause analysis for unplanned energy loss events would reveal a very significantly higher proportion of human factor-related causes. However, this cannot be substantiated, as the information required for root cause analysis is currently unavailable. Again, the sharing of root cause analysis information could result in global gains.

3.3 AVAILABLE CAPACITY

The other element of reference unit power is available capacity (P), the indicator of which is energy availability (EAF). EAF is made up of both generation supplied and generation available but not supplied. The indicator that relates solely to generation supplied to the grid is the capacity factor (CF).

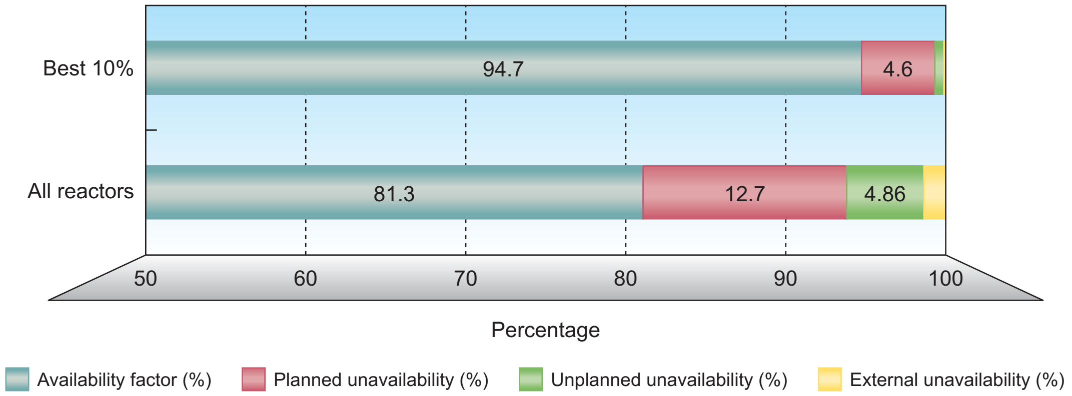

Figure 17: Availability of Reactor Units (2006-2008)

Figure 17 shows that best performers have significantly larger planned and actual availability than others. In other words, they maximize their availability and minimize the amount of planned and unplanned unavailability compared to other units. For best performers then, planning for success and being able to stick to that plan is important.

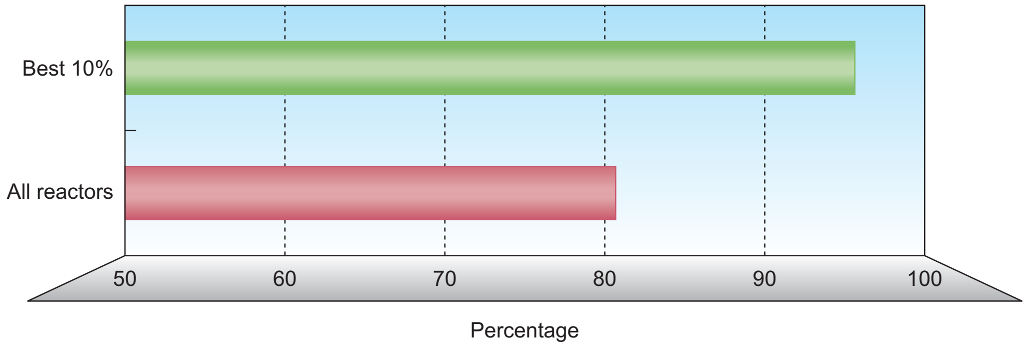

Figure 18: Recent Capacity Factors (2006-2008)

In Figure 18 the difference in achieved capacity factors between the best performing 10% of units and the global average is clear to see.

The best capacity factor performers in the years 2006-2008 represent a range of technologies[13], vendors, regions[14] and countries suggesting that performance is independent of these choices. Best performers in these years achieved a median CF of 95.68%.

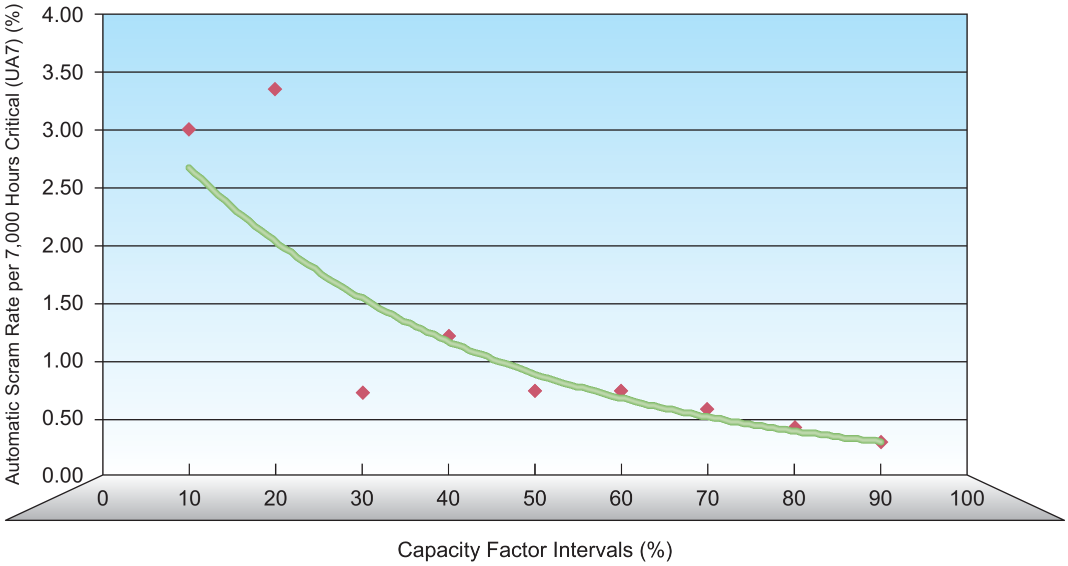

Figure 19: Average Number of Automatic Scrams for Capacity Factor Intervals (2006-2008)
Trend line inserted through data points.

The indicator Automatic Scram Rate per 7,000 Hours Critical (UA7) relates to plant safety as it provides a measure of undesirable and unplanned thermohydraulic and reactivity transients requiring reactor scrams. It also therefore provides an indication of how well a plant is being operated and maintained and indeed, it is seen in Figure 19 that there is a link between plant safety and performance. A higher CF is linked to lower numbers of automatic scram rates. Therefore work done to improve automatic scram rates will have a benefit to the plant's CF. Scrams are caused by a wide range of issues including equipment problems and human performance issues as well as nuclear safety practices. Good performers manage across these operational issues to achieve both productivity and safety.

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[13] PWR, BWR and PHWR all appear in the list of best performers.
[14] North America, Far East Asia and Europe all appear in the list of best performers.

4 Factors Affecting Capacity

The Capacity Optimization Working Group has identified the following factors as affecting capacity:

1. Outage Execution

- Duration
- Frequency
- Scope
- Management
- Cost

2. Equipment Reliability

- Human performance
- Lifecycle management, asset management
- Predictive maintenance
- System redundancy
- Component reliability
- System diagnostics
- Culture of operations
- Digital controls

3. Regulatory Environment

- Licences
- Working regulations
- Market conditions
- Baseload vs load following
- Fuel cycles (12, 18, 24 months)
- Greenhouse gas emissions
- Licensing process
- Public relations
- Fuel cycle
- Surveillance extensions (component level)
- Outage operations requirements

4. Organizational Factors

- Human resource availability
- Training and education requirements
- Knowledge management
- Governance (centralized/decentralized)
- Financial decision making – financial steering model

5. Engineering

- Design changes
  - Power uprates
  - Design upgrades
  - Design change processes (life cycle management)
- Fuel
  - Design
  - Reliability
  - Front and back end (limiting factor)
- Environment
  - Water
  - Heat sink
  - Hurricane
  - Earthquake
- Grid stability
- Life extension
- Ageing – longer term management
- Thermal performance

6. Safety Performance

- Scram rate
- Radiation exposure
- Industrial safety
- Fuel reliability
- Safety system availability
- Safety culture

7. Finances

- Cost benefit
- Investment analysis
- Operating and Maintenance (O&M) cost
- Capital cost

8. Supply Chain Processes

- Contract management
- Partnerships and alliances
- Procurement

5 Conclusions

1. The industry's steady progress in raising the capacity factor has halted in the last few years.
2. Age does not have a significant effect on the capacity factor.
3. Technology choice between the predominant reactor designs does not have a significant effect on the capacity factor.
4. Best performers achieve both higher available capacity and lower unavailable capacity than other reactors.
5. The vast majority of loss is within plant management control.
6. Planned losses have the biggest impact (except in the case of GCRs).
7. Combined maintenance and refuelling outages are the single biggest cause of loss – this is more pronounced for the best performers who comparatively reduce other causes of loss.
8. The biggest cause of unplanned loss is an extension to a planned outage – suggesting not only short outages but also well-planned and executed, predictable outages are beneficial.
9. Plant equipment problems and failure is the largest direct cause of unplanned loss, with the turbine and auxiliary system responsible for the highest proportion of unplanned losses.
10. Plants with higher capacity factors have lower numbers of automatic scrams.

These conclusions have been drawn using indicators of performance for the global fleet and the best performing 10% of the global fleet. To draw more locally applicable conclusions would require the sorting and analysis of the data by factors such as region and reactor type.

Further, greater detail and understanding in each area would certainly be achieved by performing case studies and root cause analysis. Root cause analysis applied to unplanned energy losses would result in information which could be applied to achieve gains globally. However, adequate data collection and sharing must be undertaken by the industry in order to enable this analysis to be performed. Case studies, which are used to share operational experience, are more appropriate for examining best practice in managing planned energy loss.

More than a third of the current global nuclear fleet is over 30 years of age; ageing is therefore a significant concern for the industry. It is therefore warranted that more detailed investigation(s) should be performed to analyse for currently hidden trends of if and how ageing affects capacity. Costs related to maintaining capacity of ageing plants will be crucial to strategic business and investment decisions. Equally the operations of ageing reactors will need to take into account how managing plant capacity now may affect the plant's ability to function at the same level in the future.

While this paper has given an overview of global trends and highlighted some main issues and findings, to determine a nuclear power plant's optimal capacity both the boundary conditions and balance between the factors that affect capacity need to be understood and quantified. Therefore identifying a plant's optimal capacity would require advanced mathematical modelling due to its complex multifactoral dependence. However, even without this modelling tool, lessons learnt from suitable root cause analysis and case studies can still be implemented to achieve global improvement in fleet capacity.

With the potential benefits in safety, economics, security and environmental performance available, it is clear that further work in optimizing the current global nuclear fleet's capacity has merit.

6 Definitions

For more detailed definitions and descriptions of accepted measurement techniques for the following values and performance indicators please refer to either:

- IAEA PRIS or
- World Association of Nuclear Operators Performance Indicator Programme Reference Manual

6.1 VALUES

Reference Unit Power (RUP)
The maximum power capability of the unit under reference ambient conditions. Reference ambient conditions are environmental conditions representative of the annual mean (or typical) ambient conditions for the unit. The reference unit power remains constant unless permanent modification or permanent change in authorization that affects the capacity is made to the unit. [MW(e)]

Reference Energy Generation (REG)
The energy that could be produced if the unit were operated continuously at full power under reference ambient conditions. The reference energy generation is determined by multiplying the reference unit power by the period hours. [MW(e).h]

Available Capacity (P)
The maximum net capacity at which the unit or station is able or is authorized to be operated at a continuous rating under the prevailing condition assuming unlimited transmission facilities. [MW(e)]

Energy Loss (Total Unavailable Capacity) (EL)
The energy which could have been produced during the reference period by the unavailable capacity. It is comprised of PEL, UEL and XEL. [MW(e).h]

Energy Generated (Generation Supplied) (EG)
The net electrical energy supplied during the reference period as measured at the unit outlet terminals, i.e. after deducting the electrical energy taken by unit auxiliaries and the losses in transformers that are considered integral parts of the unit. [MW(e).h]

External Energy Losses (XEL)
The energy that was not supplied due to constraints beyond plant management control that reduced plant availability. [MW(e).h]

Planned Energy Loss (PEL)
The energy that was not supplied during the period because of planned shutdowns or load reductions due to causes under plant management control. Energy losses are considered to be planned if they are scheduled at least 4 weeks in advance. [MW(e).h]

Unplanned Energy Loss (UEL)
The energy that was not supplied during the period because of unplanned shutdowns, outage extensions or load reductions due to causes under plant management control. Energy losses are considered to be unplanned if they are not scheduled at least 4 weeks in advance. [MW(e).h]

6.2 INDICATORS

Capacity Factor (CF)
The ratio of the energy which the unit produced over the period, to the reference energy generation over the same time period.
CF (%) = (EG/REG) x 100
This indicator reflects the actual energy utilization of the unit for electricity and heat production.
(Note: this is sometimes known as Load Factor (LF))

Energy Availability Factor (EAF)
The ratio of the energy that the available capacity could have produced during this period, to the reference energy generation over the same time period.
EAF (%) = [(REG–PEL–UEL–XEL)/REG] x 100
This indicator reflects the unit's ability to provide energy.

Energy Unavailability Factor (EUF)
The ratio of the energy losses during the period due to unavailable capacity to the reference energy generation over the same time period.
EUF (%) = (EL/REG) x 100 = 100–EAF = PUF+UUF+XUF
This indicator reflects all the unit's energy losses.

Unit Capability Factor (UCF)
The ratio of the energy that the unit was capable of generating over a given time period considering only limitations under plant management control, to the reference energy generation over the same time period.
UCF (%) = [(REG-PEL-UEL)/REG] x 100
This indicator reflects the unit's energy production reliability.

Planned Capability Loss Factor (PCLF)/Planned Unavailability Factor (PUF)
The ratio of the planned energy losses during a given period of time, to the reference energy generation over the same time period.
PCLF/PUF (%) = (PEL/REG) x 100
This indicator reflects planned activities that cause energy loss such as refuelling and maintenance.

Unplanned Capability Loss Factor (UCLF) /Unplanned Unavailability Factor (UUF)
The ratio of the unplanned energy losses during a given period of time, to the reference energy generation over the same time period.
UCLF/UUF (%) = (UEL/REG) x 100
This indicator reflects outage time and power reductions that result from unplanned equipment failures or other conditions.

External Unavailability Factor (XUF)
The ratio of the external energy losses during a given period of time, to the reference energy generation over the same time period.
XUF (%) = (XEL/REG) x 100 = UCF-EAF
This indicator reflects energy loss caused by events beyond plant management control.

Forced Loss Rate (FLR)
The ratio of all unplanned forced energy losses during a given period of time to the reference energy generation reduced by energy generation losses corresponding to planned outages and unplanned outage extensions of planned outages during the same period.
FLR (%) = FEL/ [REG-(PEL+OEL)] x 100
where FEL is unplanned forced energy losses and OEL is unplanned outage extension losses.
This indicator reflects the plant's ability to maintain systems for safe electrical generation when it is expected to be at the grid dispatcher's disposal.

Automatic Scram Rate per 7,000 Hours Critical (UA7)
The number of unplanned automatic scrams (reactor protection system logic actuations) that occur per 7000 hours of critical operation. This indicator reflects plant safety (the number of undesirable and unplanned thermal-hydraulic and reactivity transients requiring reactor scrams).
UA7 = (total unplanned automatic scrams while critical) / (total number of hours critical) x 7000

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