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Trending Fuel Design Parameters for Competitive Advantage

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The primary competitive advantage of commercial nuclear power over other baseload generating sources has been and continues to be the stability of fuel expense. Fuel contributes about 30% of total nuclear production costs and we believe this percentage will rise moderately as non-fuel production costs continue their decline. This places some urgency on seeking and implementing improvements in fuel utilisation by both suppliers and consumers to keep nuclear power competitive.

The nuclear operating company as a fuel consumer can evaluate trends over the past operating cycles in its search for improvement in fuel utilisation. Some fuel parameters that have received attention recently are contracting strategies, fuel reliability, and higher exposures for discharged fuel.

Another topic for trending could include the group of technical reload design parameters that are calculated and must fall within licensing limits for each reload of fuel. The operating company and the fuel supplier discuss acceptable margins to the design limits prior to fabrication of reload fuel assemblies. Have the margins changed? Are the parameters similar to other plants? Just introducing the topic through a trends analysis might lead to a more challenging environment between the buyer and supplier. This in turn can create the ultimate "win-win" outcome where both the buyer and supplier end up in better position than they would have if the challenge had never been made.

This paper suggests that the reactor operating company can gain competitive advantage by evaluating trends in technical reload design parameters. Using a single page survey form and e-mail to 23 LWR operating companies throughout the world (15 in the USA), we collected during two months in 1999 technical reload design data for 21 reactors. The data covers the past four operating cycles of 18 PWRs and 3 BWRs. Only the PWR data is covered in this paper.

Our primary conclusion is that the following two types of benefits may be achieved by taking a proactive position when setting the margins to the design limits:

- One is in cost management resulting from improved fuel utilisation (the number and enrichment of fuel assemblies delivered).
- A second is the confirmation that reactivity management is being purchased consistent with the objectives of the operating company, with

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some recognition of the tradeoffs being made among the reload design parameters. We define reactivity management as the planned changes in subcritical and critical conditions based on approved changes in reload design and operating parameters.

Improved fuel utilisation and reactivity management have considerable value, but if they are pushed too aggressively they can cause reactor downtime through operating problems and possibly fuel failures. The marginal value of fuel utilisation and reactivity management depends on whether or not the reactor's fuel management is in transition or is near equilibrium conditions, how well the core performance predictions have been in the past compared to actual operating performance, and the occurrence of any performance anomalies and/or fuel failure. Without question, satisfying reactor safety margins is always the top priority followed by the quest for lower fuel costs and tighter analysis of reactivity management.

The reactor operating company must have some experience with reload design methods to be proactive and challenging in the reload design arena. Fuel design engineers need to work closely with their suppliers or they need to do independent analysis to understand the implications of changes in design licensing limits and fuel utilisation. The operating companies have varying degrees of capability to work with their supplier or to do independent analysis, but the companies with more advanced capabilities are more likely to change their cycle-dependent operating limits in order to improve plant operations or economics. We believe a trends analysis of reload design parameters will lead to better understanding of the options available in reload design that affect plant economics. This type of proactive commitment is consistent with the guidelines issued by the US Nuclear Regulatory Commission (NRC) and the Institute of Nuclear Power Operations (INPO).

Taking Advantage of Changing Trends

A little more than a decade ago there was a major effort at Pacific Gas & Electric Company (PG&E) to prepare information for the Diablo Canyon nuclear power plant cost of construction rate case hearing. At the time, unit 1 had completed two operating cycles and was in an estimated 120 day refuelling outage, and unit 2 was about to complete its second operating cycle and enter an estimated 84 day refuelling outage.

The Diablo Canyon final cost of construction was US$5.5 billion. The rate case hearing was expected to take about two years at considerable expense. On one side, the California Public Utilities Commission (CPUC) Division of Ratepayer Advocates (DRA) advised in 1987 that only US$1.1 billion of the total costs be allowed in the rate base as recoverable expense. On the other side, PG&E was seeking full cost recovery.

PG&E senior management initiated discussions with the CPUC and the State of California regarding alternate mechanisms that could be used to substitute for the rate case hearing. The one that prevailed was "pay for performance" in which PG&E as the operating company agreed to pay all Diablo Canyon production costs in return for a price per kWh of generation from the plant. If the two unit plant generated electricity, there would be revenue. If the reactors were at reduced power or down altogether, there would be little or no revenue.

Diablo Canyon production costs at that time were about US$30 million per month. As part of the settlement, PG&E had taken a US$500 million after tax write-off that would "virtually eliminate 1988 earnings".[1] The cash dividend to shareholders was cut by 25%, the first reduction in 55 years. The possibility for unplanned or extended outages took on a new meaning, since these outages would require enormous sums of cash outflow with no cash inflow. On the face of it, this was a risky undertaking considering the uncontrolled risks of generic shutdowns by the NRC and escalating market prices for fuel supply.

During the settlement negotiations in the spring and early summer of 1988, PG&E's Nuclear Fuel Management group evaluated numerous Diablo Canyon fuel expense scenarios based on different plant capacity factors and fuel prices. Senior management used these annual and operating cycle fuel expense forecasts in the composite of Diablo Canyon production costs to arrive at negotiable kWh generation price levels. The Nuclear Fuel Management group was responsible for fuel supply prices. Another group was responsible for plant capacity factors, which have considerable effect on nuclear fuel expense for a given fuel loading plan.

Figure 1 shows average US plant capacity factors from 1974 through 1988, and Diablo Canyon plant capacity factors in 1985 through 1988. These trends in capacity factors were no doubt used by both sides in the settlement negotiations to arrive at potential revenue from Diablo Canyon generation. In the press releases immediately following the settlement, the CPUC DRA said that the settlement was equivalent to a US$2 billion disallowance and the evaluation of the benefits to ratepayers was based upon this valuation. "The primary assumption supporting the $2 billion equivalent disallowance is that over its term Diablo Canyon will operate at a 58% capacity factor."[2] The DRA and the State Attorney General essentially bet against PG&E's ability to operate Diablo Canyon efficiently.

Figure 2 shows U_3O_8 annual average spot market prices from 1974 to 1988. This trend had some influence on the internally generated U_3O_8 price forecast used within the Nuclear Fuel Management group to calculate Diablo Canyon nuclear fuel expense. As buyers, and in preparing information for the settlement negotiations, the Nuclear Fuel Management group did not want to estimate low and end up short of funds, so there was a tendency to be conservative on the high side. There was social unrest in several producing countries at the time, and there were also what seem now like bizarre attempts within the US to place embargoes, restrictions and "graduated tariffs" on uranium imports regardless of market price. For example, US Senator Symms introduced a bill (S.980) in April 1987 to embargo Australian uranium due to the wool and livestock trade policies of New Zealand and their denial of port access for US naval ships suspected of carrying nuclear weapons.

Figure 3 shows what happened to US nuclear plant average annual capacity factors and U_3O_8 spot market prices. Capacity factors improved measurably,

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particularly for Diablo Canyon, and spot prices remained low the entire decade following the Settlement.

Business was good for the Nuclear Power Generation Business Unit at PG&E in the years following the settlement. Earnings generated from Diablo Canyon contributed substantially to the company’s net income. PG&E employees, contractors and union members worked together to communicate and accomplish Diablo Canyon performance goals, and to change the way some work was done to become more efficient. Plant safety was always the top priority and Diablo Canyon continues to be among the best operated plants in the world.

A similar situation as in 1988 for Diablo Canyon now exists for some reactors with respect to their reload design parameters. There is room for improvement. Some initiative must be undertaken by the operating company and the fuel supplier. A relatively easy first step is a trends analysis of relevant reload design parameters. To be sure, the benefits are minuscule compared to those discussed above, but the emphasis on risk-based decision making is the same. There are savings in the range of US$500 000 annually over two or three operating cycles due to better utilisation of margins in design parameters. The ability to utilise the excess margin is based largely on the analytical capability within the operating company.

Limiting Parameters of Reload Design

The US NRC reviews and approves the analysis methods used to design and analyse reload fuel. The fuel supplier and/or the utility company must use an approved methodology to determine the fuel design and core loading pattern, and to perform the reload safety evaluation (RSE) for each cycle. This analysis effort is performed consistent with the licensing basis for the specific reactor.

The US Code of Federal Regulations, 10CFR50.36, establishes criteria for technical specification of limiting conditions of operation for a nuclear reactor.[3] Based on these criteria, each reactor in the USA has its own set of limiting condition values that are defined in the plant technical specifications. Many of these limiting condition values are dependent on the fuel and reload core design. The operating company can change these limiting values in the plant technical specifications if the supporting analysis is done consistent with an approved methodology. This is a big job.

The NRC also permits specification of operating limits for cycle dependent variables. This is done in a Core Operating Limits Report (COLR) which is a supplement to the plant technical specifications. The operating company can make changes in the COLR without prior approval of the NRC, but the approved methods that were used to define the core operating limits must be included by reference in the technical specifications.

Minor changes to approved fuel designs are sometimes accomplished without NRC review and approval, but a safety evaluation of the changes must be performed and approved by the plant Safety Committee before the fuel is loaded into the reactor.

Many licensees have changed their operating limits over time, especially if they have increased the length of their operating cycles. For some operating companies with skilled engineering staff, the trend is toward longer cycles and designing reload fuel with less margin to the operating limits. There are several key parameters that dominate the reload design decisions and fuel utilisation. These are explained later, but for a PWR they are:

- FΔH — fuel rod power peaking is limited to a certain value;
- MTC — moderator temperature coefficient needs to be negative at power;
- SDM — the shutdown margin needs to be greater than the limit value;
- Fuel burnup — the peak fuel pin burnup must not exceed the limit.

For the BWR these are:

- MCPR — the minimum critical power ratio must be greater than the limit;
- Hot excess reactivity — sufficient reactivity must be available for manoeuvring the reactor;
- SDM — the shutdown margin needs to be greater than the limit value;
- Fuel burnup — the peak fuel pin burnup must not exceed the limit.

A few US reactor operating companies have considerable experience in reload design and safety analysis methods. These companies have an integrated reload design and safety analysis process and can perform both steady state and transient analysis for licensing applications, with the fuel vendor performing the LOCA analysis (some perform their own LOCA analysis). These companies complete much or all of the RSE by themselves. We refer to these companies as Category 3 later in the paper (highest is most capable).

Several more operating companies have qualified a steady state physics analysis process and have NRC approval to perform steady state analysis for licensing applications. Their computer code set may be the same or different than the fuel vendor codes. In addition, they have engineering procedures, linking or auxiliary codes, statistical quantification of the core model accuracy, and persistent efforts toward model validation. For these companies, the RSE is a shared responsibility with the fuel vendor, with the vendor performing the transient and LOCA analysis. We refer to these companies as Category 2.

It is also common in the US that an operating company has a fuel staff that performs scoping fuel management studies, core depletion calculations, and plant support for physics testing, expected critical positions, and core follow calculations. These companies have a lattice physics code, a 3D nodal code, and a fuel economics code, any or all of which may be the same or different than the fuel vendor codes. These companies have the ability to perform multi-cycle scoping studies and to assess alternative loading patterns, but all design and licensing analysis responsibility lies with the fuel vendor. We refer to these companies as Category 1.

A Category 0 reactor operating company is one that essentially does nothing with respect to reload design activities. All of the fuel management and reload

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analysis is performed by the fuel vendor, and there are no internal capabilities at the operating company. However, these companies must perform oversight fuel design review and control activities per 10CFR50 Appendix B, III.

INPO and NRC Guidelines for Reload Design Analysis

The NRC and INPO have released guidance on the scope of reload design analysis performed by reactor operating companies. Utility Resource Associates (URA) has conducted a number of assessments for operating companies regarding their performance of fuel management and safety analysis, based on the INPO and NRC guidelines. A few of the recommendations from INPO[4] follow.

Recommendation 1 — The operating company should have the ability to:

- accurately model and predict core performance, and explain differences between various analytical models;
- understand reactivity management implications of different designs;
- understand potential consequences of mixed core designs (different fuel designs provided by the same vendor, or varying designs from different fuel vendors).

Recommendation 2 — The operating company should be able to:

- define and follow the performance of interfaces between work performed by the fuel vendor and the operating company;
- control design inputs and calculation methods;
- define and follow the performance of technical verification involving core design and reload analyses.

Recommendation 3 — The operating company should have the ability to:

- apply industry experience to unintended changes such as axial flux shifts, control rod insertion anomalies, and reload analysis errors;
- apply core monitoring and prediction capabilities.

Trending core design parameters relates directly to INPO SOER96-2. Trending is a tool for engineers and senior nuclear management to use in their risk assessment of each reload. What is the trend of the design patterns over the past few reloads? Is risk being increased, and if so, are there attendant operational and fuel utilisation benefits? For example, if the value of shutdown margin has decreased over the past cycles, have other design parameters changed to offset this so that the risk of an operational problem has not increased? Or has the operating company chosen a high shutdown margin over the past cycles as an element of its reactivity management policy?

We summarise the NRC's position with regard to licensees and their use of analytical methods[5] in the following statement issued on 8 February 1983 in NRC Generic Letter 83-11: "We (NRC) encourage utilities to perform their own safety analyses since it significantly improves their understanding of plant behaviour." Checking calculations, integrating the safety and the reload design processes, trending data, and discussing the trends with the fuel vendor are all complimentary to this intent.

Supplement 1 to NRC Generic Letter 83-11 was issued on 24 June 1999.[6] This further describes licensee activities to perform their own reload design and safety analysis, and the need to compare calculations against published benchmarks and analyses of record. It also provides the opportunity for operating companies to build their modelling capability based on fuel supplier generic topical reports or those prepared by other organisations (such as the Electric Power Research Institute) without formal submittals to the NRC.

The balance of this paper presents samples of PWR data that we collected over two months in 1999 and our evaluation of the sample charts. Our evaluation of this data is relative to reactivity management and fuel utilisation, and relative to the capability that exists at the operating company.

Survey Data on Technical Reload Design Parameters

URA sent via email a one page survey form to 15 operating companies in the USA and eight operating companies in other countries. We attempted to collect an equal amount of PWR and BWR data but the overwhelming response was on the PWR side.

We received a response from 80% of the domestic companies. One operating company in Europe responded by sending back a survey form with much of the requested data. We have a relational database of this information and will continue this effort to collect PWR and BWR design trend data and make the data available to operating companies for benchmarking purposes, while keeping the name of the reactor unit and operating company confidential.

We show data for three PWR reload design parameters that can be evaluated for competitive advantage. These three parameters are FΔH (FdH in charts), Shutdown Margin (SDM), and Isothermal Temperature Coefficient (ITC). We also show data derived from the survey to represent a fuel utilisation parameter.

The parameters can be evaluated on a single reactor basis to explain a trend, or on a comparative basis to look for economic or operational benefits. To do the comparative analysis, the data should be grouped by similar reactor types with an understanding of the operating and reactivity management philosophy for the plants being compared.

*F*D*H*

FΔH is the fuel rod integral power peaking factor. It is the ratio of the power produced by the highest fuel rod to that of the power produced by the core average fuel rod. The limit for this value is set in the technical specifications or the COLR.

FΔH is influenced by the choices made in the number of feed assemblies and the enrichment of feed assemblies. Depending on the reactor, longer operating cycles and higher batch average burnups can be obtained by an increase in FΔH. Higher batch average burnups can be achieved without an increase in FΔH but normally at the expense of using more burnable absorbers and/or inserting relatively more assemblies in the core at lower enrichment to spread the power distribution. Another advantage of a higher FΔH is that power is

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reduced from assemblies at the edge of the core, which improves neutron economy.

The value of F∆H reported in the final design documentation is often increased by 5–10% by the fuel designer to allow for conservatism due to the uncertainty in the methodology, the operating cycle history, and the tolerances in fuel assembly manufacturing and measurement data. This extra margin is used by the designer depending on the aggressiveness or the conservatism of reactivity management chosen by the operating company.

Five of the 18 PWRs surveyed had increased their F∆H operating limit value over the past four cycles. Figure 4 shows samples of the F∆H trend data for three of the reactors. The left side *y*-axis and the solid line in each chart represent the F∆H reported value for the operating cycle. The right side *y*-axis and the dashed line represent the percentage of the F∆H value to the allowed limit.

Unit D shows an aggressive design practice because each operating cycle has F∆H consistently above 95% of the limit. Unit B shows the trend of increasing F∆H and decreasing F∆H margin with each subsequent reload. This unit increased its cycle length by over 20% from cycle *n*-3 to cycle *n*.

Unit K shows an increase in margin in cycle *n* compared to the prior cycles. However, the F∆H limit was increased in cycle *n* and the value of F∆H was increased to take advantage of the new higher limit. The operating company increased the limit by about 7%. Based on the prior cycles, we would expect that Unit K will ramp back up above 95% of its F∆H limit value in the next cycle, assuming there are no operating problems.

One estimate is that a 5% increase in power peaking design limit permits a reduction in fuel cycle cost by US$150 000 to US$200 000 per cycle.[7]

Figure 5 shows trend lines of the F∆H data pooled by operating companies in Categories 3, 2 and 1. The dashed trend line shifts down from about 98% for the Category 3 companies down to around 93% for the Category 1 companies. The Category 3 companies are taking advantage of their analytical capabilities, and it is prudent for the Category 1 companies to be more conservative with the allowed margin.

EOC Shutdown Margin

Shutdown margin (SDM) is the amount of reactivity by which a reactor is maintained in a subcritical state. The SDM is an important parameter for the safety evaluation performed during the reload design process. Typically the SDM limit is more demanding at the end of the operating cycle (EOC), and thus the parameter examined is the SDM at EOC. SDM is influenced by the choices made by the core designer in setting the core loading pattern for each reload. The placement of fresh fuel versus burnt fuel in the core locations which contain control rods, and the amount of burnable absorbers in the assemblies in both the rodded and unrodded locations influence the amount of shutdown margin.

Some reactors start with less SDM because of the number and placement of control rods that were established at the time of the plant design. For example, some reactors have larger SDM because they have fewer and relatively larger diameter control rods than other reactors. The amount of SDM in a specific reload core is also a function of how aggressive or conservative the operating company is relative to the utilisation of excess margin. The operating company's overall reactivity management philosophy influences how much SDM is designed into an operating cycle.

Figure 6 shows samples of the SDM data for three reactors that responded to our survey. The left side *y*-axis and the solid line in each chart represents the EOC SDM calculated value, in units of $\%\Delta k/k$. The right side *y*-axis and the dashed line represent the percentage that the SDM value is above the limit. For example, if the operating limit for EOC SDM is 1.5 and the calculated value for the reload design EOC SDM is 3.0, then the value on the right side of the chart is equal to 200% (of the limit).

Unit L shows an aggressive design practice. Each reload cycle has SDM consistently near the limit. Unit J shows a consistent SDM which has considerable excess margin. Unit F illustrates a decrease in the SDM with each subsequent cycle.

Figure 7 shows trend lines of the SDM data pooled by operating companies in Categories 3, 2 and 1. The dashed line shifts up from a level 120% for Category 3 to an increasing trend for Category 1 with an average around 160%. As with the $F\Delta H$ data, the Category 3 companies are using their analytical capabilities to squeeze excess margin out of the design. This can result in better fuel utilisation.

Isothermal Temperature Coefficient

The isothermal temperature coefficient (ITC) is the change in reactivity per unit change in the moderator, cladding and fuel pellet temperature. ITCs are measured at the startup of each new cycle to ensure that the reactor will operate as designed. The moderator temperature coefficient (MTC) is the design parameter of interest and the Hot Full Power MTC must be a negative value to ensure the safe operation of the reactor. The MTC is directly related to the ITC, and since the ITC is the measured parameter it is often used as the key variable in reload design.

The ITC is influenced by the choices made by the designer in setting the burnable poison loading in the new fuel assemblies. The value of the ITC measured at the beginning of the operating cycle (BOC) may be positive or negative depending on the specific plant's licensing limit. When the reactor is operating at full power the MTC must be negative for all reactors. The conservatism of the ITC at BOC (i.e. the amount it is more negative than the limit) is a function of the operating company's use of ITC margin.

Figure 8 shows samples of the survey data for ITC (in units of pcm/°F). The left hand *y*-axis represents the ITC calculated value.

Unit E shows an aggressive design practice. The aggressive practice here is that the company is designing to a consistent, slightly positive ITC value.

Unit B shows a consistently negative ITC. Unit G shows a trend towards more negative ITC with considerable excess margin. The possible reason for this drop may be a higher burnable absorber loading.

Figure 9 shows trend lines of the ITC data pooled by operating companies in Categories 3, 2 and 1. The trend line shifts down from Category 3 to Category 2. As with the F∆H and the SDM data, it appears that the Category 3 companies are using their analytical capabilities for competitive advantage. In the case of ITC, designing to an ITC that has excess margin (i.e. a more negative value) can cause high fuel costs due to possible excess use of burnable absorber. The use of burnable absorber has design tradeoffs with F∆H, the loading pattern and enrichment split.

Fuel Utilisation

We used an "Rfactor" to quantify fuel utilisation. The Rfactor is the number of MW-days generation during a cycle divided by the equivalent pounds U_3O_8 loaded in fresh fuel assemblies for that cycle. The Rfactor is energy-out divided by U_3O_8-in to represent fuel utilisation. High numbers are good.

The Rfactor is influenced by the designer's choice of loading pattern and the effort to design right up to the peak rod burnup limit. Loading patterns that have high average discharge burnup with minimal amount of F∆H margin result in very good fuel utilisation. Another factor that influences Rfactor is the fuel design. A newer fuel design that produces more energy for less enriched product improves fuel utilisation.

A third factor that influences Rfactor is the reactor operating history. Fuel utilisation is biased upward if there is energy carried from the prior cycle to the current cycle as the result of an unexpectedly early shutdown in the prior cycle. We eliminated three data points from the analysis among the total of 72 (18 reactors with four operating cycles of data) due to this type of bias caused by an early cycle shutdown.

The influence of tails assay is embedded in our definition of Rfactor. We used a 0.3% tails assay for the new regions of fuel for all of the reactors.

Figure 10 shows the trend line of Rfactor and cycle length for operating companies with Category 3, 2 and 1 capabilities.

For the Category 3 companies, there is a trend of higher fuel utilisation for longer operating cycles. These companies are loading higher assays of enriched product with fewer assemblies and fewer kgU compared to earlier cycles of equivalent energy. They are also attaining higher batch average burnups than in prior cycles. Four of the five reactors in this category have used 4.9w/o U-235 or higher in one or more of the past four operating cycles. None of the five has had fuel performance problems over the past four cycles that we are aware of.

There is a larger scatter in the data and a slightly decreasing trend in fuel utilisation for companies in Categories 2 and 1. In general, the F∆H margin and SDM for these companies are greater than the Category 3 companies.

Some of these reactors in the Category 2 and 1 level of our survey have fuel costs that are among the lowest in the USA. Fuel utilisation and fuel expense are related in some ways, but have fundamental differences in their units of measure. One is in energy out, the other is in financial currency out, per unit of fuel supply in.

Conclusion

In any market, competition provides incentives to both suppliers and consumers to improve products. Each needs to initiate ideas to stay competitive in its own market. Examples over the past ten years include auto and truck tyres that stay inflated when punctured, eyeglass frames that can be realigned when sat upon, and rechargeable batteries.

We recognise the outstanding progress made in the past decade by the suppliers and consumers of nuclear fuel assemblies. Innovative fuel designs make the assemblies stronger, lighter and with less uranium loaded for the same energy output. Research and development to support these success stories is costly. Many technical improvements in LWR fuel design have been introduced during a period when fabrication prices have been dropping. Reactor capacity factors also are much higher, along with continued safe operation.

There are opportunities that lie ahead, but we have to dig them out, not unlike the improvements that have been made in uranium ore production. Reload design improvements can be made at some reactors simply by understanding tradeoffs that are being made in the reload design technical parameters in order to use excess margin. Some operating companies are not as involved in the process as others. We never stay the same, we either get better or worse at what we do and participation is critical in order to improve.

One way for the reactor operating company to seek improvements in either direct fuel cost or in reactivity management is to trend the technical reload design parameters over the past operating cycles and understand the meaning and impact of changes in the trend lines. This can lead to a challenging environment within the fuel management group and with the fuel supplier, perhaps to the betterment of both.

Our experience is that operating companies with access to advanced fuel design skills are able to procure more of what they want in a reload than the operating company that places less emphasis on the design process. The idea is to not waste margin, but to know how much of it is being used at what cost. The survey data presented in this paper is admittedly rough but it supports this thesis.

If the operating company decides to evaluate its reload design margins, the value in squeezing margin out of reload designs depends on the specific situation at the reactor, but it can be easily in the range of US$500 000 annual fuel expense reduction over two or three operating cycles. A trend analysis of the reactor's significant reload design parameters is a good start in the right direction.

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Figure 1. Average annual capacity factors, for all US plants and for Diablo Canyon (DCPP).

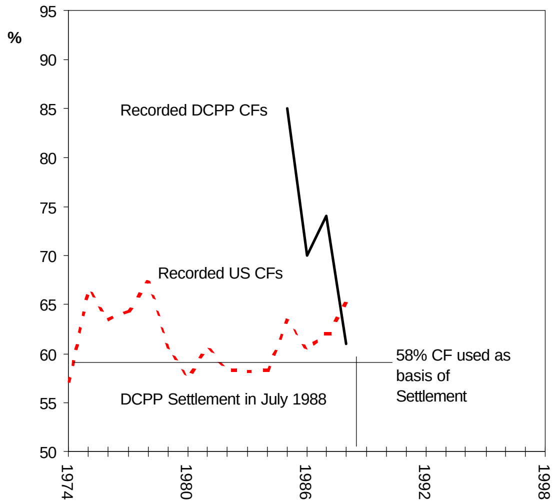


Figure 2. U_3O_8 average spot market prices (US$).

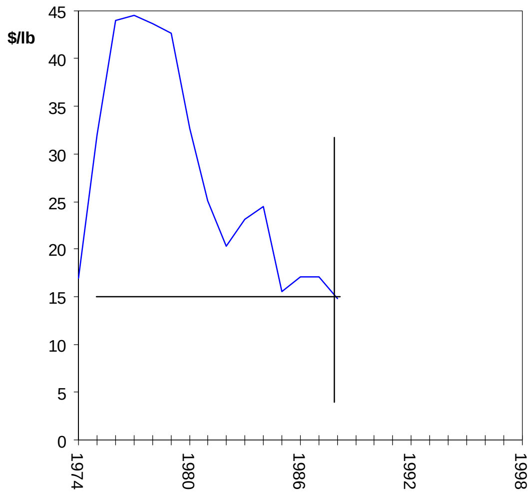
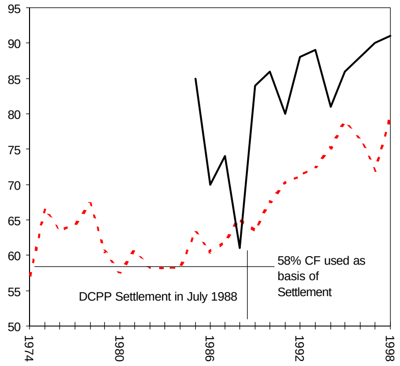


Figure 3. Plant capacity factors and U_3O_8 spot market prices (1974–98).



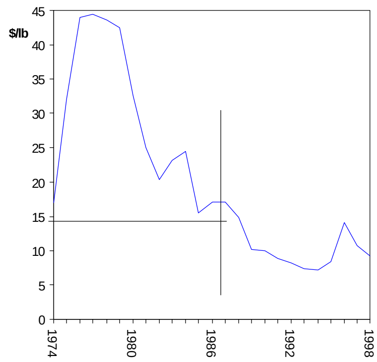
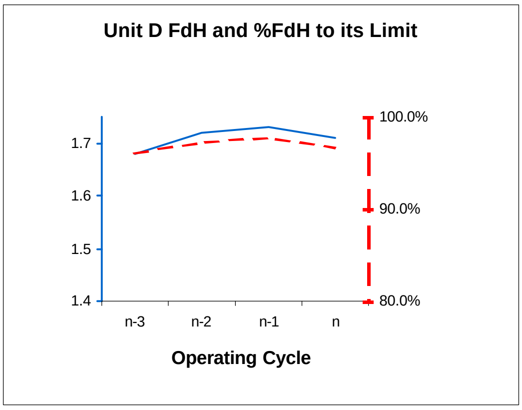
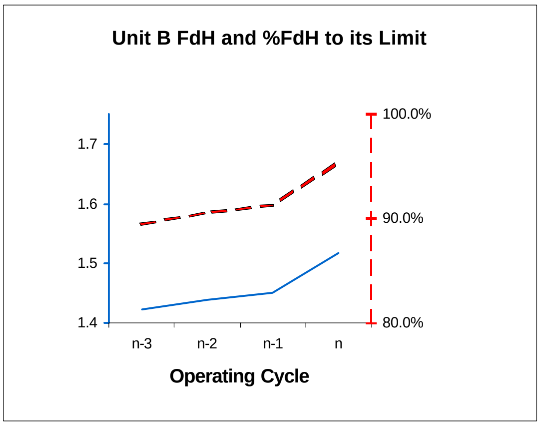


Figure 4. Sample FDH, and FDH as a percentage of its limit, trend lines.





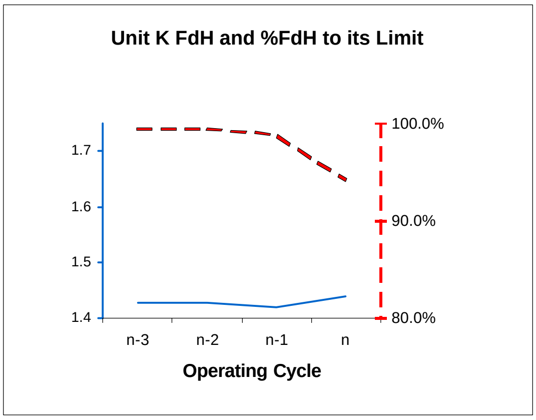


Figure 5. FDH trend lines, by capability Category 3, 2 and 1.

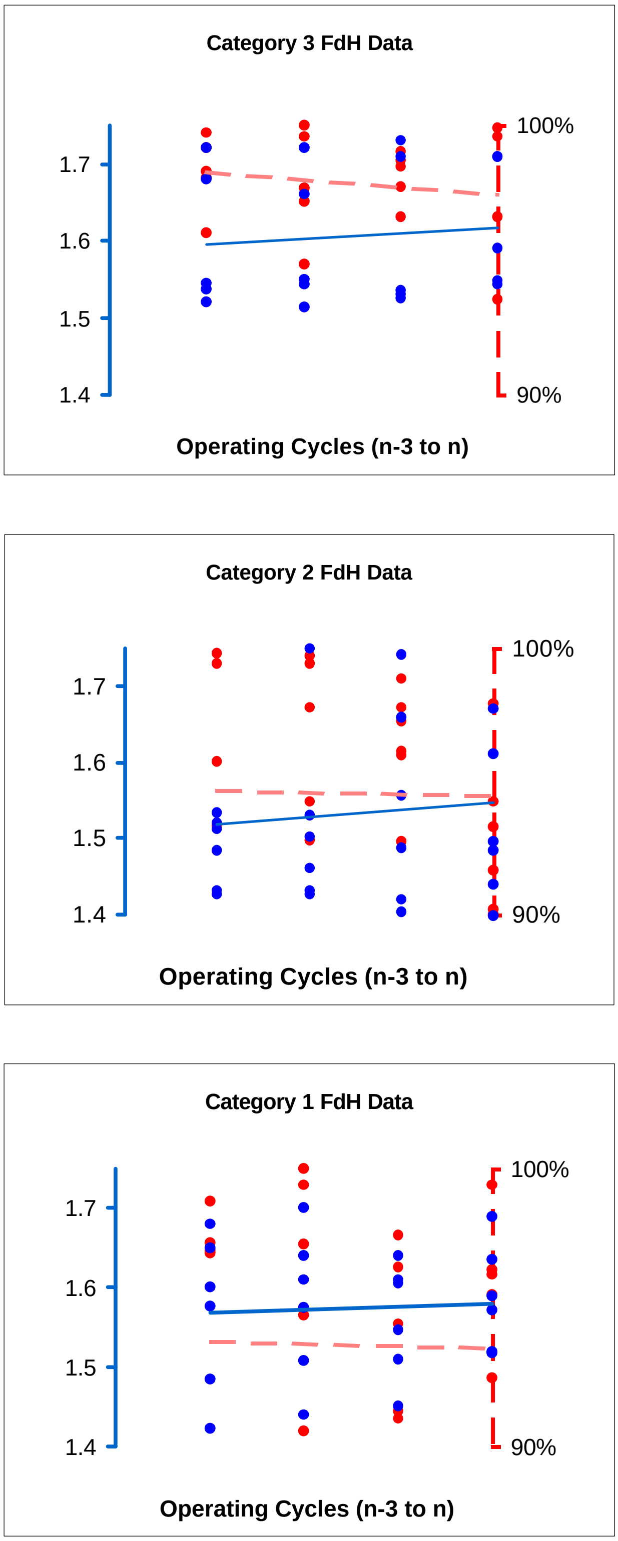
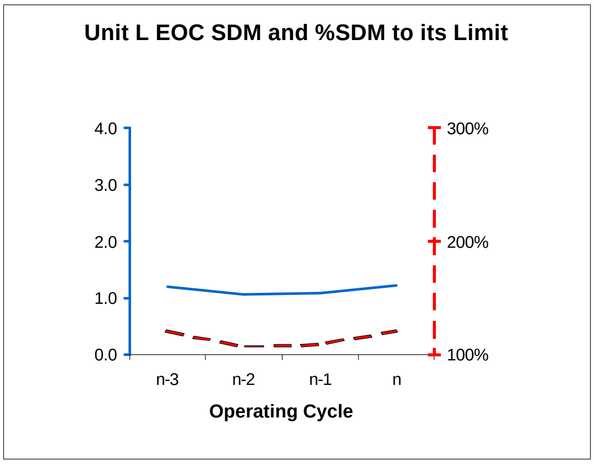
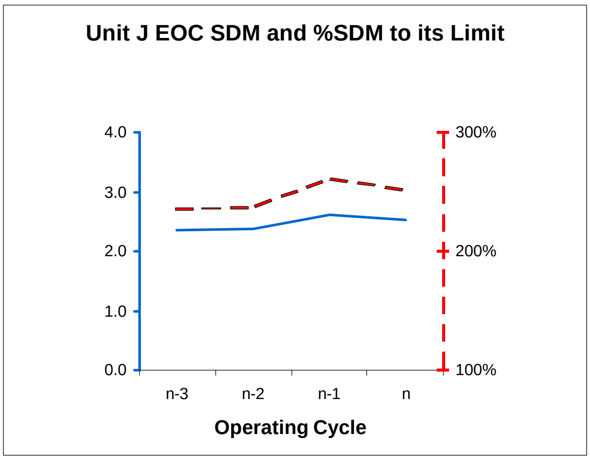


Figure 6. Sample SDM, and SDM as a percentage of its limit, trend lines.





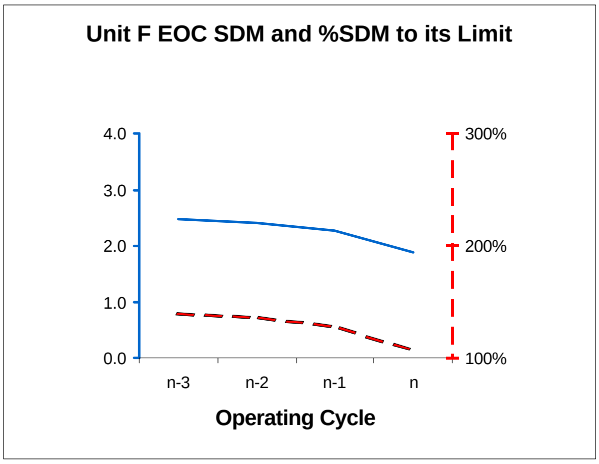


Figure 7. SDM trend lines, by capability Category 3, 2 and 1.

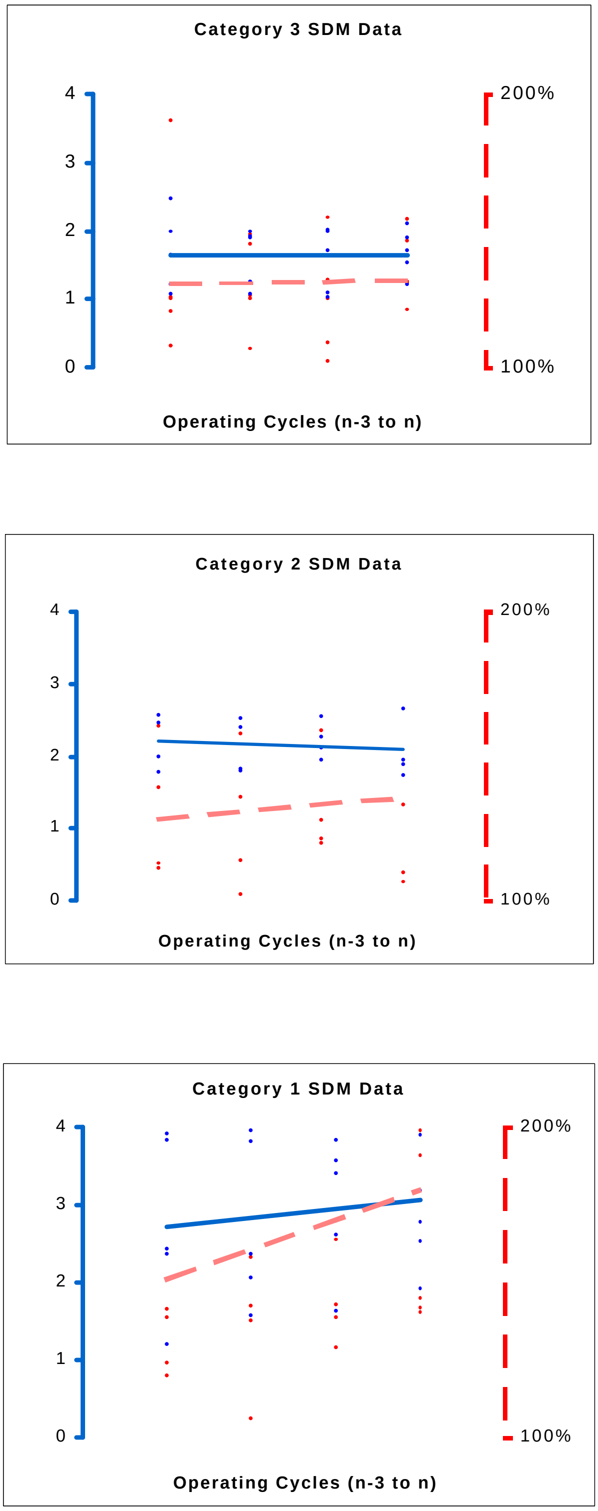


Figure 8. Sample ITC trend lines.

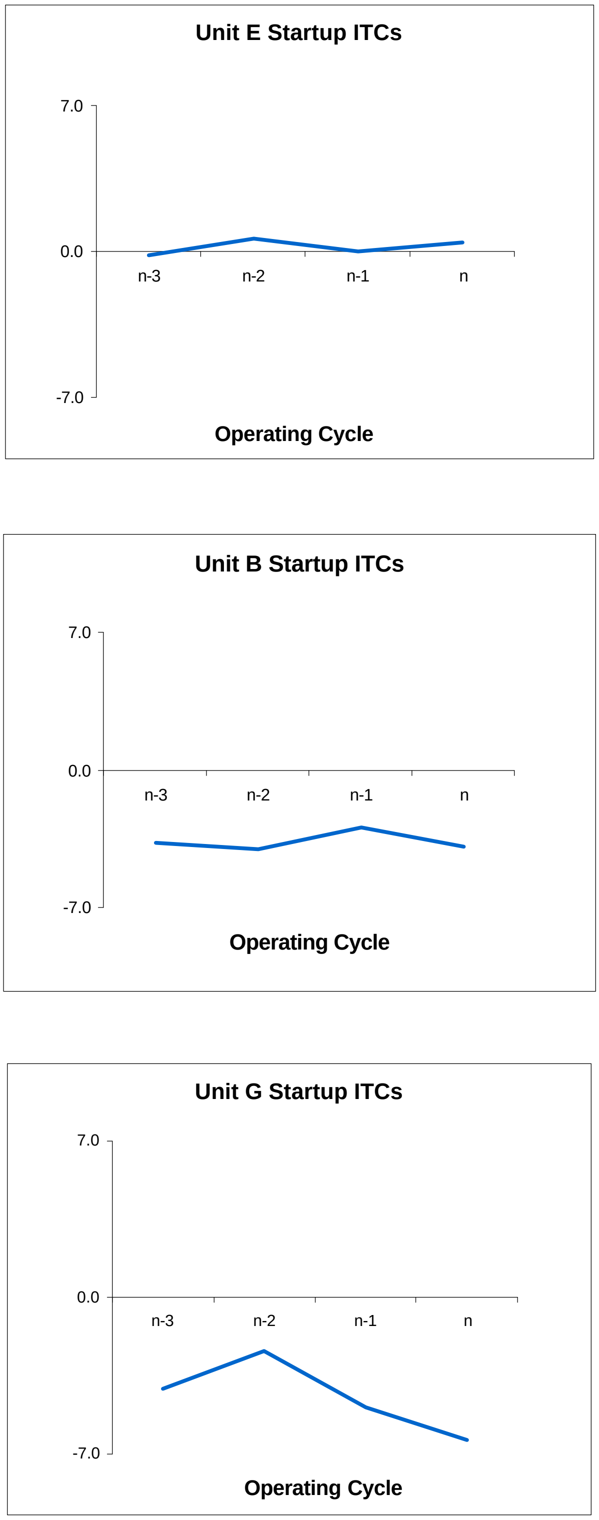
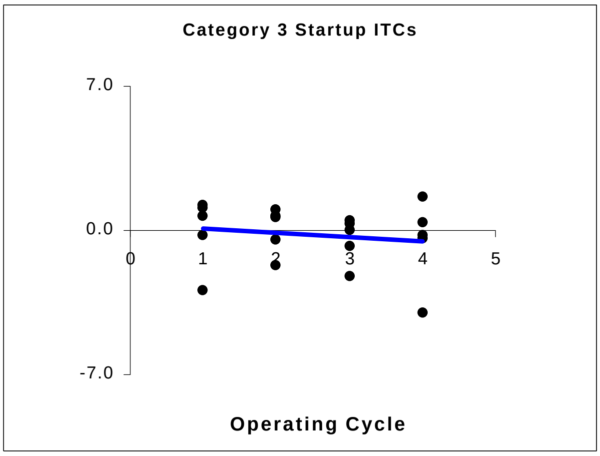
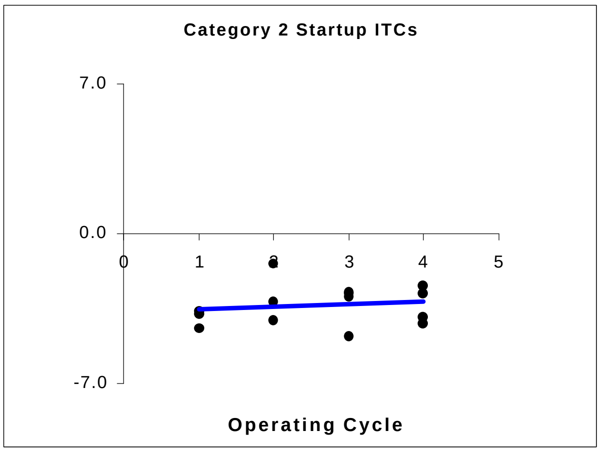


Figure 9. ITC trend lines, by capability Category 3, 2 and 1.





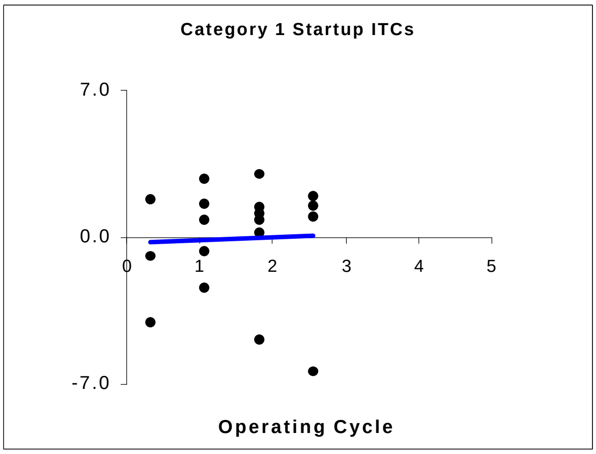


Figure 10. Fuel utilisation trend lines, by capability Category 3, 2 and 1.