UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, D.C. 20555-0001

September 25, 2002

MEMORANDUM TO: ACRS Members and Staff

FROM: August W. Cronenberg, Staff Engineer

SUBJECT: Margins Paper & View-graphs for PSA-Detroit Meeting, Oct. 6-9, 2002

Attached, for your information, are copies of a paper entitled *Margin reductions for Re-Licensed/Uprated Plants and Risk Implications* and the associated view-graphs, which is to be presented at the Detroit-PSA conference the week of Oct. 6th. This paper summarizes final ACRS Fellow responsibilities.

Let me take this opportunity to thank each and everyone of you for a very rewarding experience during these past 7 year with the ACRS. The Fellow work has been quite interesting and I believe the type of investigative efforts that are needed in the agency and worthwhile input to ACRS. Again, my thanks.

For PSA-2002, Detroit (Oct. 6-10/02)

Margin Reductions for Re-Licensed/Uprated Plants and Risk Implications

by

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ABSTRACT- A case-study examination is presented regarding the impact of power uprates and plant renewal on component margins for nuclear power plants. Results point to margin reductions to design limits for specific plant components, owing to both power increase and plant life extension. Such margin reductions have been noted by the Advisory Committee on Reactor Safeguards (ACRS), particularly in the context of potential compounding effects on margin degradation stemming from multiple licensing actions and risk/safety implications.

1. INTRODUCTION

Projected electrical power shortages have lead to recent industry initiatives for plant license renewal, power uprates, and requests for a longer fuel cycle at higher burnups. Of the approximately 100 nuclear units currently in operation, it is estimated that upwards of 80 may apply for license renewal beyond their current 40 year period. A number of plants have likewise applied for power increases of 15-% or greater. Although each such licensing action is reviewed by the US Nuclear Regulatory Commission (NRC) to assure that the current body of regulations are satisfied and that plants continue to operate safely, there may be concerns regarding the safety and risk implications of margin reductions, particularly with respect to potential compounding effects stemming from multiple licensing actions for an aging fleet of US nuclear power plants.

A recent study [1] of operational incidents noted from License Event Reports (LERs) for power uprated plants point to potential synergistic/compounding safety implications for power uprates in conjunction with fuel life extensions to higher burnup, and uprates in association with plant life extension and affiliated aging phenomena. Examples cited in that study include control rod insertion problems noted in high-burnup/high-power fuel assemblies for the uprated Wolf Creek plant (burnup/uprate synergism), as well as pipe failure events via corrosion/erosion effects (aging/uprate synergism), notably at the uprated Callaway-PWR and Susquehanna-BWR plants. In addition, Khatib-Rahbar et al [2] evaluated the risk impact associated with a 14.7-% power increase for the Swiss Leibstadt-BWR plant. Results of that study show an increase in risk which stems from the increased radioactive inventory and the time acceleration of events for postulated accidents due to the increased decay heat level at uprated conditions. They demonstrate a 30-% increase in activity risk (radioactive release activity times frequency) associated with the 14.7-% power uprate. They also note [3] a reduced operator response time to core uncovery events owing to the higher decay power at uprated conditions, as well as a higher containment failure probability for severe accidents due to higher containment over-pressure at the higher power.

Although the NRC has moved toward a more risk informed approach to regulation, requirements for risk information and margin impact to support individual licensing actions are minimal. For example, although the License Renewal Rule allows for risk considerations to enter into the review process, the use of risk information is an option left to the applicant. The basis for renewal approval largely rests on the regulatory principle that a nuclear plant can continue to operate for so long as it complies with its current licensing basis (CLB) and continues to satisfy all regulatory requirements, i.e. rules stipulated in the Code of Federal Regulations (CFR), including 10CFR-Part 54 for license renewal. This approach stems from the regulatory framework that compliance with the CLB and CFR rules provides assurance of adequate protection. There is no explicit regulatory requirement to assess risk implications associated with margin reductions.

The fact remains however, that although regulatory limits are not exceeded, actual margins to aging degradation limits are being reduced. For example, at the end of 60 years mechanical components will be closer to their fatigue and corrosion limits than at the end of the original 40 year license, the reactor vessel will be less ductile due to the accumulated effects of irradiation embrittlement, and so on. If a complete PRA were performed that would describe aging effects appropriately at 40 years of life, and then again at 60 years, one would expect to see an increase in risk measures such as CDF and LERF, due to an expected higher failure probability of long-lived components subjected to 20 more years of service. Unfortunately PRA technology is not currently capable of modeling the effects of aging degradation, therefore we do not have a quantitative measure of the risk significance of margins reduction due to aging.

The ACRS has been supportive of License Renewal (LR) because the implementation of the LR rule requires establishment of licensee-directed programs for aging-management that are comprehensive and provide reasonable assurance that any age-associated increase in risk for the extended period of operation should be small. This conclusion is predicated on the assumption that such programs are capable of identifying age degradation, and such degradation is acted upon before related regulatory limits are exceeded. Recent events however call this assumption into question. For example we note the hot- leg weld leak at the V. C. Summer plant, where inspections using ultrasonic testing (UT) just a year before license renewal did not reveal weld cracking; thus an example of insufficient identification of age degradation. Likewise, we note the substantial vessel head corrosion by boron at the Davis-Besse plant, where early signatures of boron leakage were known but not addressed; thus an example of failure to act before regulatory limits were exceeded. Such events challenge the assumption that age-management programs will indeed identify age-degradation and be properly acted upon.

2. MARGIN(S) IN THE REGULATORY PROCESS

Webster's definition of margin is: *a) spare amount, or measure allowed for contingencies, b) a bare minimum below which something becomes no longer desirable.* Such definitions are rather broad, thus it is not surprising that margin, as used in the regulatory process, is somewhat vague. The most explicit use of regulatory margin is probably that embodied in the General Design Criteria (GDC) for Nuclear Power Plants, which today are given the weight of federal law as Appendix A of 10CFR50, (Code of Federal Regulations). Table 1 provide several examples of margin as provided by the GDC; indicating that margin is presented only in a very broad sense. In its practical application, margin requirements are more explicitly spelled out as Regulatory Guides, which often stipulate that the design of plant systems, structures and components (SSC) adhere to national standards, such as the ASME Boiler & Pressure Vessel (BPV) code. The ASME -BPV not only provides standards for the design, construction, manufacture and testing of reactor components, but also specific design limits regarding allowable limitations of stress, temperature, pressure, corrosion, etc. The primary objective of the ASME Code is the "protection of life and property and to provide a margin for deterioration in service as to give a reasonably long, safe period of usefulness". The ASME design limits for specific components form the basis of our investigation of the impact of power uprates and plant renewal on component margins.

Figure 1 provides an illustration of the margin space associated with the reactor pressure vessel (RPV), which typically have an ASME prescribed design limit of 1,250-1,500 psig for BWRs, 2,700-2,800 psig for PWRs, and a factor of safety of 5 or greater to the as-fabricated failure pressure (P_f). In the case study presented in this paper, we make use of Hatch-BWR plant conditions, where the shaded shows what is referred to as "licensee margin". The first Hatch uprate involved in increase in reactor operational pressure from its original value of 1005 psig to 1035 psig for the first 5-% power uprate. Thus, the "Licensee Margin" to the vessel design limit of 1,250 psig is somewhat reduced at the higher power, although neither the "design limit" nor the "safety margin" are violated. It is recognized that the regulatory process makes this margin space available to the licensee. However, it is important to note that "overall margin" is still reduced, which may be best illustrated from the perspective of a delta-margin (Δ_{Margin}) concept:

$$\Delta_{Margin} = [\text{Component Failure Pressure} - \text{Component Actual Pressure}]$$

For the new Hatch plant, the original 1995 reactor operating pressure was 1005 psig and the vessel is assumed in a non-degraded/new-condition; thus Δ_{margin}-1 in Figure 1 applies. Now compare this with conditions associated of the first power uprate that occurred in 1995, where the reactor pressure was increased by 30 psi to 1035 psig. Since the reactor vessel is not a component that is subject to periodic replacement, the margin to the vessel failure (P_f) can be assumed reduced, owing to such processes as irradiation embrittlement and corrosion effects during its 20 years of operation. In this case Δ_{Margin}-2 applies. In a broad sense the overall margin is thus narrowed or reduced, though neither the "design limit" nor the "safety margin" is violated. It is this reduction in overall margin, or Δ_{Margin}, that is the subject of this paper.

To examine the margin impact of uprates and license renewal, a case study was made for the Hatch-BWR plant, since it received approval for two power uprates (5-%, 8-%) and a 20-year license extension. It is emphasized that we have not attempted to make a detailed evaluation of the safety or margin impact of such licensing actions for Hatch; thus the results presented here should not be taken as a reflection of any measure of Hatch plant safety. Rather the Hatch examination is provided solely as an illustrative example and typical of what might be expected for many BWR plants. For power uprates the margin impact was assessed from consideration of changes in plant thermal-hydraulic operational and Design Basis Accident (DBA) conditions, as compared with the pressure/temperature design limits for specific components. For plant life extension, changes in margins were based on predictions of fatigue limits for a number of passive components.

3. MARGINS IMPACTED BY POWER UPRATES

The Hatch Units 1 and 2 are sister GE-BWR/4 plants of similar design and having much the same operating conditions. Figure 2 illustrates basic plant characteristics for direct-cycle GE-BWR/4 plants. Unit-1 received its operating license in 1974 at an initial thermal limit of 2436MWt, while Unit-2 received its initial license in 1978, also at 2436 MWt [4]. Both plants requested and received power uprate approvals in 1995 [5], each to a new limit of 2558MWt, representing a 5-% increase. This was followed by a second uprate approval [6] in 1998 to 2763 MWt for both units, representing an 8-% power increase from prior power level and an effective 13.4-% increase from the initial licensed power. In their second uprate proposal, the licensee stated that the power increase was based upon limitations and modification costs related to the balance-of-plant (BOP) equipment, and not upon design limitations within the nuclear steam supply system (NSSS). Although the first uprate of a 5-% involved a 30 psi increase in reactor operating pressure, the second 8-% power uprate did not, rather it was accomplished by a flattening of core power and higher net steam flow. Table 2 summarizes plant operating parameters for both units at initial and uprated power conditions, where parameter values are based on conditions provided in Refs. [4-6].

An increase in power stems from some increase in coolant enthalpy from the core, achieved by an increase in primary system pressure, temperature, net coolant through-flow, or some combination thereof. Changes in "margins" for the primary coolant system can thus be assessed from associated changes in thermal-hydraulic parameters, as compared to design temperature/ pressure limits. Table 3 presents a summary of Hatch operational conditions stemming from two power uprates as compared to primary piping design limits. As indicated higher steam-line piping temperatures and pressures are evident at uprated conditions, resulting in some reduction in margin to their design limits.

The most notable change in component margins for power uprates however is generally associated with predictions for design basis accidents (DBA), such as under loss-of-coolant accidents (LOCA). Table 4 summarizes DBA-LOCA stress predictions for various vessel components. A predicted stress of 64.5 ksi is indicated for bolting to the vessel access cover plate at the first uprate compared to the design limit of 107.7 ksi, which translates to 40-% margin. The margin is shown to be reduced to 16-% at the second uprate, owing to higher predicted bolt stresses (90 ksi) associated with increased blowdown loads and the use of a more conservative stress model employed in the second uprate analysis. In other cases the change in margin with power is less, which partly stems from the fact that the parameter in question (stress, temperature) remains well below the design limit.

4. MARGINS IMPACTED BY LICENSE RENEWAL

With regards to plant life extension, margin trends were estimated for several passive components for which time-limited aging analysis (TLAA) was performed as part of the Hatch license renewal application [7]. TLAA estimates for piping largely centers on estimates of the cumulative usage factor (CUF) for cyclic loadings during the period of extended operation. Such TLAA-CUF estimates essentially involve an assessment of the stress impact of various operational and off-normal transients which contribute to the total cumulative fatigue to the component. The ASME Boiler & Pressure Vessel code requires CUF value less than one for all Class-1 components; thus margin is simply one minus the predicted value of CUF for that component. In its most simple form CUF can be expressed as:

$$CUF = N_{OBE}/f_1 + N_{Scram}/f_2 + N_{Start}/f_3 + \ldots\ldots N_{other}/f_n$$

where

N_{OBE} =number of operating basis earthquakes
N_{Scram} = number of reactor scrams
N_{start}= number of reactor startups
N_{other} = other operational transients

and f_1, f_2, f_3, and f_n are scaling factors indicative of the maximum number of allowable cycles for a particular transient or event and its associated impact on fatigue. When the extended license term is considered, NRC requires that Class-1 components also have a CUF less than one. If CUF is found to be greater than 1.0, then that component is subject to special inspection considerations or other remedial action during the license extension period [8].

For the Hatch plant, the licensee in conjunction with various subcontractors [9], estimated the cumulative usage factor (CUF) for all Class-1 piping and components at their 1998 condition, as well as at the end of 40 and 60 years of operation. The CUF estimates were based on a review of the operating history for each unit and include estimates of the total startup events, scrams, shutdowns, boltup operations, etc. Table 5 summarizes piping CUF and margin estimates for a number of passive components as a function of plant lifetime. As shown, CUF equals 0.56 for feedwater piping at 40 years, which increases to 0.72 at

60 years. For some passive components the residual CUF margin at the end of the 60-year extension period is quite minimal. For example, CUF is estimated to be 0.95 for the torus suppression-pool at the end of 60-years, indicating only 5-% residual margin at the end of the license renewal period.

5. DISCUSSION/CONCLUSIONS

Although such estimates are crude, nevertheless they point to a general trend of component margin reductions to design limits both power uprates and plant life extension. It is recognized that the regulatory process makes this margin space available to the licensee, and that neither Design Limits or Safety Margin are violated for the Hatch plant. From the perspective of Figure 1, such margin reductions can be viewed as "bottom-up" reductions to design limits.

It is important to recognize that margin reductions can likewise occur from a "top-down" view of Figure 1. Examples of top-down margin reductions included component degradation due to age related processes, such as fatigue and corrosion/erosion effects; or stemming from power uprates where corrosion effects can be exacerbated at higher temperatures/flow rates or loss of vessel ductility at the higher neutron fluence a uprated conditions. As an example we cite the increase in predicted corrosion/erosion rates using CHECWORKS for the Clinton-BWR power uprate, indicating >80-% increase in the wear rate for the scavenging steam line owing to higher uprate flow/temperature conditions, i.e.

Clinton-BWR	Pre-Uprate	Post-Uprate	Increase
Power, MWt	2894	3473	20-%
Vessel Steam Flow, lb/hr	12.4E+6	15.1E+6	22-%
Scavenging Steamline CHECWORKS-Wear Rate, mils/yr	38 (data=20)	70	84-%

Examples of actual exacerbated corrosion/erosion events include the piping failures at the uprated Callaway-PWR and Susquehanna-BWR plants. Likewise, we note the recent cracks in the control rod drive (CRD) nozzles for the Oconee plant, the severe localized corrosion of the Davis-Besse reactor vessel head associated with boric acid leakage from cracked CRDs, and the observations at the V. C Summer plant of a weld leak in a hot-leg nozzle which had not been identified by ultrasonic testing performed a year before license renewal approval. For each of these events, "top-down" margin degradation was significant; indeed for CRD cracks and piping failures there was no residual margin, while essentially nil margin can be ascribed to the severely corroded Davis-Besse reactor vessel head.

Of particular concern to the ACRS is the inability for early detection of margin degradation of the magnitude exemplified by these events.

It is noted that the margin estimates presented in this paper were for individual components and for separate licensing actions, i.e. either power increase or life extension. The more difficult problem is to translate changes in component-specific margins to the plant as a whole, i.e. a holistic measure of margin impact for the plant. Also of compelling interest is the integration and compounding effect of margin degradation owing to multiple licensing actions. Such margin integration efforts were beyond the scope of the work reported here but are recommended for future investigation.

It is finally noted that although the NRC has set upon a course of making greater use of risk information in the regulatory process, current regulatory reviews of license renewal applications and power uprates are largely being addressed from a deterministic approach and as separate/non-associated actions. Although uprate and renewal reviews include an evaluation of safety related components and systems to assure that current regulatory requirements are satisfied and that such equipment perform their intended function; uprate and renewal regulatory reviews are essentially done independently of one another. A consequence of this approach is the absence of a holistic or integrated assessment of plant safety stemming from multiple licensing actions. Clearly component margins to design limits are being consumed by the higher demands imposed by uprates and life extension for the same plant. Vessels are more embrittled at 60 years than at 40, while mechanical components are closer to their fatigue limits as the plant ages. Likewise, higher pressures and temperatures at increased power leave less margin to their design limits, while higher decay heat leaves less time for mitigative actions, and higher radionuclide inventories pose a potentially greater source term. With some development efforts, it is believed that PSA techniques can provide a more integrated assessment of margin impact owing to the combined influence of plant life extension and power increase. In view of these findings, the following conclusions are made:

- Margin reductions to design limits for specific plant components were noted for both power uprates and license renewal. Although plant-to-plant variations exist, one is drawn to the conclusion of generic margin reductions for such licensing actions, owing to longer component duty times and higher operational conditions. Component margin reductions appear most notable for design basis accidents (DBA).

- This study points to the need for considerably more information with regards to margin impact on individual components and the plant as a whole, particularly for power uprate applications. The development of a Standard Review Plan (SRP) for Power Uprates, with regulatory guidance on margin impact would go a long way in remedying this situation. On the other hand, regulatory requirements specified in the Standard Review Plan (SRP) for License Renewal, exemplified by aging/fatigue analysis requirements for passive components, provide a transparent means for assessing the margin impact for plant life extension.

- Margin estimates presented in this study were largely noted for individual components and for separate licensing actions. No attempt was made in this study to translate changes in component specific margins to that for the plant as a whole, or to assess the compounding effects of multiple licensing actions. With some development efforts, it is believed that PSA techniques can provide a more integrated assessment of margin impact. Such margin integration efforts are recommended.

DISCLAIMER: The views expressed in this paper are solely those of the authors and do not necessarily represent the views of the ACRS as a body or that of the Commission.

REFERENCES

1. A. W. Cronenberg, D. Powers, and R. P. Savio, *Operational Events Noted for Power Uprated Plants and Potential Safety Implications,* 10th International Conference on Nuclear Engineering, ASME-ICONE10, Arlington, Va, (April 14-18, 2002).

2. M. Khatib-Rahbar, E. G. Cazzoli, A. Kuritzky, and U. Schmocker, *An assessment of the Risk-Impact of Reactor Power Upgrade for a BWR-6 MARK-III Plant,* Proc. of PSAM.-3 Meeting, Crete, Greece, (1997).

3. M. Khatib-Rahbar and U. Schmocker, *Regulatory Evaluation of the Leibstadt PSA,* Energy Research Report, ERI/HSK-95-303, (Mar. 1996).

4. U.S. Nuclear Regulatory Commission, *Safety Evaluation Report Related to the Operation of the Edwin Hatch Nuclear Plant,* NUREG-0411, (1978).

5. Southern Co., *Extended Power Uprate Licensing Submittal-1995: Edwin I. Hatch Nuclear Power Plant,* (Jan. 1995).

6. Southern Co., *Extended Power Uprate Licensing Submittal-1997: Edwin I. Hatch Nuclear Power Plant,* (August 1997).

7. Southern Company, *Edwin I. Hatch Nuclear Plant License Renewal Application,* Docket: 50-321 & 50-366, (Feb. 2000).

8. U. S. Nuclear Regulatory Commission, *Safety Evaluation Report: License Renewal of the Edwin Hatch Nuclear Plant, Units 1 & 2,* Docket: 50-321 & 50-366, (Feb. 2001).

9. Structural Integrity Associates, Inc., *Development of Class-I Piping Fatigue Formulas and Fatigue Usage Estimates for the Hatch Nuclear Power Plant, Units-1 &* 2, Structural Integrity Associates Report, SIR-99-078, (August 1999).

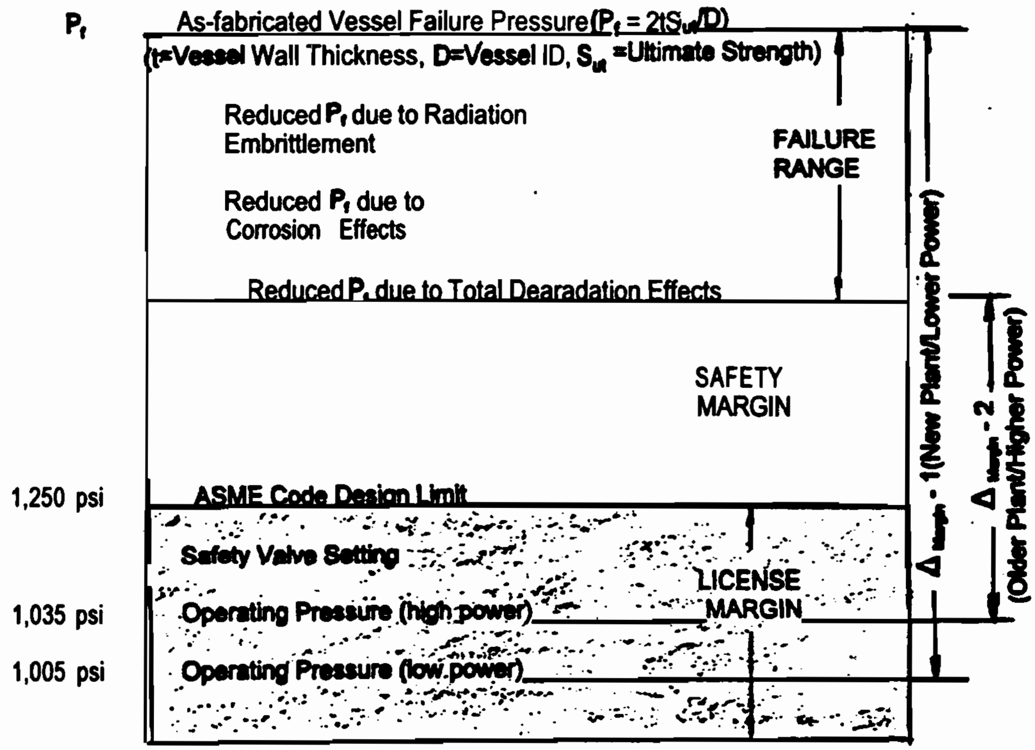

Figure 1. Illustration of margin concept for a typical reactor vessel, as used in the regulatory process.

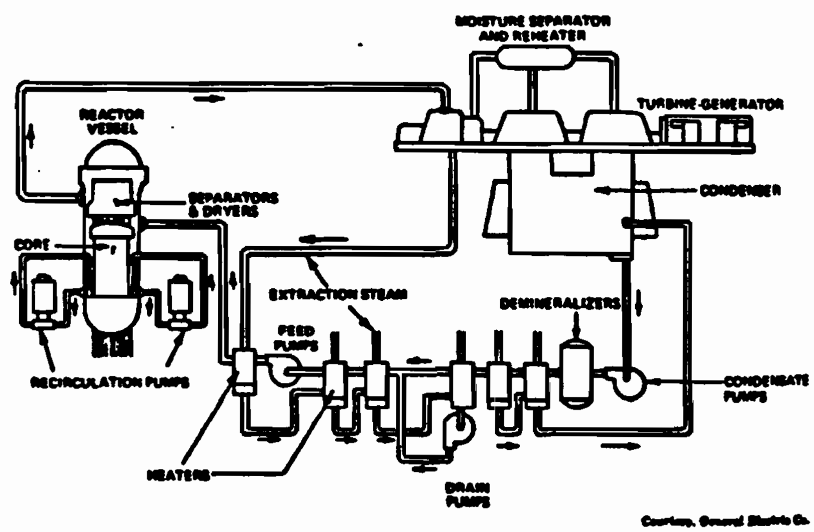

Figure 2. Illustration of the essential features of the reactor coolant system for direct-cycle GE-BWR/4 type plants.

Table 1. Margin in Appendix-A 10CFR50: General Design Criteria

Criterion 10-Reactor design. The reactor core and associated coolant, control, and protection systems shall be designed with appropriate margin to assure that, specified acceptable fuel design limits are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences.

Criterion 31-Fracture prevention of reactor coolant pressure boundary. The reactor coolant pressure boundary shall be designed with sufficient margin to assure that when stressed under operating, maintenance, testing, and postulated accident conditions (1) the boundary behaves in a nonbrittle manner and (2) the probability of rapidly propagating fracture is minimized. The design shall reflect consideration of service temperatures and other conditions of the boundary material under operating, maintenance, testing, and postulated accident conditions and the uncertainties in determining (1) material properties, (2) the effects of irradiation on material properties, (3) residual, steady state and transient stresses. and (4) size of flaws.

Criterion 50-Containment design basis. The reactor containment structure, including access openings, penetrations, and the containment heat removal system shall be designed so that the containment structure and its internal compartments can accommodate, without exceeding the design leakage rate and with sufficient margin, the calculated pressure and temperature conditions resulting from any loss-of-coolant accident. This margin shall reflect consideration of (1) the effects of potential energy sources which have not been included in the determination o! the peak conditions, such as energy in steam generators and as required by 50.44 energy from metal-water and other chemical reactions that may result from degradation but not total failure of emergency core cooling functioning, (2) the limited experience and experimental data available for defining accident phenomena and containment responses, and (3) the conservatism of the calculational model and input parameters.

Criterion 51-Fracture prevention of containment pressure boundary. The reactor containment boundary shall be designed with sufficient margin to assure that under operating, maintenance, testing, and postulated accident conditions (1) its ferritic materials behave in a nonbrittle manner and (2) the probability of rapidly propagating fracture is minimized. The design shall reflect consideration of service temperatures and other conditions of the containment boundary material during operation, maintenance, testing, and postulated accident conditions, and the uncertainties in determining (1) material properties. (2) residual, steady state, and transient stresses, and (3) size of flaws.

Table 2. Summary of Hatch Units 1 & 2 Operational Conditions

Parameter	Hatch Unit-1 (BWR/Mark-I)			Hatch Unit-2 (BWR/Mark-I)		
Thermal Power, MWt (Year-Start)	2436 (1975)	2558 (1995)	2763 (1998)	2436 (1979)	2558 (1995)	2763 (1998)
% Power Uprate (from prior value)	--	5-%	8-%	--	5-%	8-%
Vessel Steam Flow, 10^6 lb_m/hr	10.0	10.6	11.5	10.5	11.1	12.0
Steam Dome Pressure, psig	1005	1035	1035	1005	1035	1035
Steam Dome Temp., °F	547	551	551	547	551	551
Full-Power Feedwater Flow, 10^6 lb_m/hr	10.1	10.7	11.6	10.5	11.2	12.1
Full-Power Feedwater Temp., °F	388	393	398	420	424	425

Table 3. Hatch Operational Margins

Residual Margin = [Design Limit - Value] / Design Limit (DL)		
Power, MWt	Parameter Value	Residual Margin, %
Main Steam-line Pressure (DL = 1250 psig)		
Original = 2436	1005 psig	19.6
1st Uprate = 2558	1035 psig	17.2
2nd Uprate = 2763	1035 psig	17.2
Main Steam-line Temperature (DL = 575 F)		
Original = 2436	546 F	5.04
1st Uprate = 2558	—	—
2nd Uprate = 2763	551 F	4.17

Table 4. Hatch Reactor Vessel Margins for DBA-LOCA Conditions

Residual Margin = [Design Limit - Value] / Design Limit (DL)		
Power I, MWt	Predicted Stress, ksi	Residual Margin, %
Vessel Shroud at Support Weld (DL = 15.28 ksi)		
Original = 2436	8.95 ksi	41.4
1st Uprate = 2558	9.05 ksi	40.8
2nd Uprate = 2763	—	—
Access Hole Cover Plate at Bolts (DL = 107.7 ksi)		
Original = 2436	Welded	—
1st Uprate = 2558	64.5 ksi	40.1
2nd Uprate = 2763	90.0 ksi	16.4
Jet pump at Diffuser Base (DL = 50.7 ksi)		
Original = 2436	31.5 ksi	37.9
1st Uprate = 2558	34.8 ksi	31.4
2nd Uprate = 2763	34.9 ksi	31.2

Table 5. Residual Margin Estimates from Piping Fatigue Usage Analysis for Hatch-1 Renewal (CUF at two significant figures)

Component	Unit	CUF at 40 yrs	Residual Margin, 40 yrs	CUF at 60 yrs	Residual Margin, 60 yrs
Residual Heat Removal Suction Pipe	2	0.57	43-%	0.77	23-%
Reactor Vessel Equalizer Piping	1	0.52	48-%	0.64	36-%
Core Spray Replacement Piping	1	0.16	84-%	0.19	81-%
Feedwater Piping	2	0.61	39-%	0.83	17-%
Standby Liquid Control Piping	1	0.24	76-%	0.25	75-%
Feedwater (FW), High Pressure Coolant Injection (HPCI), Reactor Core Isolation Cooling (RCIC)	1	0.56	44-%	0.72	28-%
Steam Condensate Drainage Piping	2	0.66	34-%	0.89	11-%
Main Steam Piping (Line B)	1	0.08	92-%	0.10	90-%
Main Steam Piping (Line D)	2	0.016	>98-%	0.02	98-%

Margin Reductions for Relicensed & Uprated Power Plants and Risk Implications

A.W. Cronenberg (ACRS-Staff)
M. V. Bonaca & G. B. Wallis (ACRS)
PSA Conference, Detroit (Oct 6-9, 2002)

1

Outline

- Margins in the Regulatory Process
- Margin Estimates for Power Uprates
- Margin Estimates for License Renewal
- Findings/Observations

2

Margins In the Regulatory Process

Webster (Margin):

- Spare amount allowed for contingencies
- Bare minimum below which something is no longer desirable

3

General Design Criteria (1OCFR50-App. A)

- Criterion-10: "Reactor core and associated coolant, control, and protection systems shall be designed with sufficient margin to assure acceptable design limits shall not be exceeded."
- Criterion-31: "The reactor coolant pressure boundary shall be designed with sufficient margin to assure ... it behaves in non-brittle manner and probability of rapidly propagating fracture is minimized."
- Criterion-50 : "The containment, including access openings, penetrations ... shall be designed ... without exceeding design leakage rate and with sufficient margin ... to reflect ... metal-water and other chemical reactions ..."

4

Margin Requirements More Explicitly Spelled Out

- Regulatory Guidance/Standard Review Plan (acceptance criteria for design pressure, P-T limits, stress limits, allowable materials, ductility limits, etc.)
- ASME Boiler & Pressure Vessel Code
- Am. Nat. Standards Inst. (ANSI)
- Other

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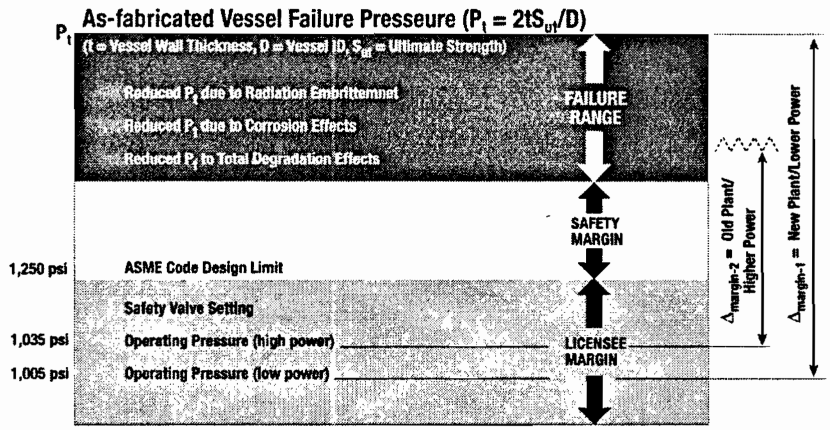
Illustration of Margin Concept for Reactor Vessel, as Used in the Regulatory Process



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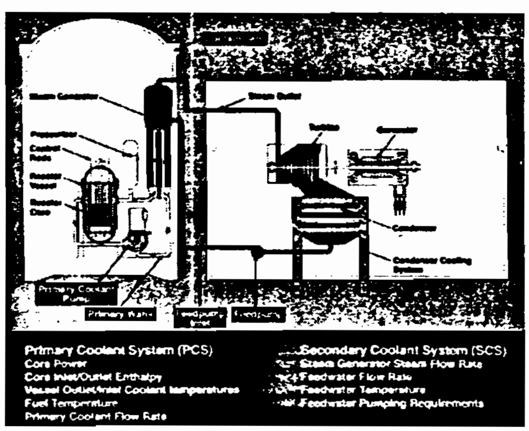
Recent Power Uprates

Plant/Type	Power Uprate	Year Start
Duane Arnold/BWR	15%	1975
Dresden-2/BWR	17%	1970
Dresden-3/BWR	17%	1971
Quad Cities-1/BWR	17%	1973
Quad Cities-2/BWR	17%	1973
Brunswick-1/BWR	15%	1977
Brunswick-2/BWR	15%	1975
Clinton/BWR	20%	1987
Arkansas Nuclear One-2/PWR	7.5%	1978

7

Impact of Power Uprates on Plant Operating Conditions



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Margin Estimates for Power Uprates (Hatch Case Study)

- <u>Hatch Plant Characteristics</u>
- - GE-BWR/4 (direct-cycle)
- - Mark-1 Containment (inverted light-bulb/ torus suppression pool)
- <u>Power Level</u>
- - 1974 Unit-1/1979 Unit-2 = 2436 MWt
- - 1995 Units 1 & 2 = 2558 MWt (5% uprate)
- - 1997 Units 1 & 2 = 2763 MWt (8% uprate)
- <u>License Renewal:</u> Approved 2001

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Summary of Hatch Operational Conditions

Parameter	Hatch Unit-2			Hatch Unit-2		
Thermal Power, MWt (Year-Start)	2436 (1975)	2558 (1995)	2763 (1998)	2436 (1979)	2558 (1995)	2763 (1998)
% Power Uprate (from prior value)	-	5%	8%	-	5%	8%
Vessel Steam Flow, $10^6 lb_m/hr$	10.0	10.6	11.5	10.5	11.1	12.0
Steam Dome Pressure, psig	1005	1035	1035	1005	1035	1035
Steam Dome Temp, °F	547	551	551	547	551	551
Full-Power Feedwater Flow, $10^6 lb_m/hr$	10.1	10.7	11.6	10.5	11.2	12.1
Full-Power Feedwater Temp, °F	388	393	398	420	424	425

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Hatch Operational Margins

Residual Margin = (Design Limit - Value) / Design Limit (DL)		
Power, MWt	**Parameter Value**	**Residual Margin, %**
Main Steam-line Pressure (DL = 1250 psig)		
Original = 2436	1005 psig	19.6
1st Uprate = 2558	1035 psig	17.2
2nd Uprate = 2763	1035 psig	17.2
Main Steam-line Temperature (DL = 575° F)		
Original = 2436	546° F	5.04
1st Uprate = 2558	–	–
2nd Uprate = 2763	551° F	4.17

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Hatch Vessel Margins for DBA-LOCA Conditions

Residual Margin = (Design Limit - Value) / Design Limit		
Power I, MWt	**Predicted Stress, ksi**	**Residual Margin, %**
Vessel Shroud at Support Weld (DL = 15.28 ksi)		
Original = 2436	8.95 ksi	41.4
1st Uprate = 2558	9.05 ksi	40.8
2nd Uprate = 2763	–	–
Access Hole Cover Plate at Bolts (DL = 107.7 ksi)		
Original = 2436	Welded	–
1st Uprate = 2558	64.5 ksi	40.1
2nd Uprate = 2763	90.0 ksi	16.4
Jet Pump at Diffuser Base (DL = 50.7 ksi)		
Original = 2436	31.5 ksi	37.9
1st Uprate = 2558	34.8 ksi	31.4
2nd Uprate = 2763	34.9 ksi	31.2

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Piping Corrosion/Erosion Estimates for Clinton-BWR 20% Power Uprate

Clinton-BWR	Pre-Uprate	Post-Uprate	Increase
Power, MWt	2894	3473	20%
Vessel Steam Flow, lb/hr	12.4E+6	15.1E+6	22%
Scavenging Steamline CHECWORKS-Wear Rate, mils/yr	38 (data=20)	70	84%

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Plant License Renewal Applications

APPROVED	UNDER REVIEW
Calvert Cliffs-1&2/PWR	Surry-1&2/PWR
Oconee-1&2/PWR	North Anna-1&2/PWR
Hatch-1&2/BWR	McGuire-1&2/PWR
ANO-1/PWR	Catawba-1&2/PWR
Turkey Point-3&4/PWR	Peach Bottom-2&3/BWR
	St. Lucie-1&2/PWR
	Fort Calhoun/PWR
	Robinson-2/PWR

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Residual Margin Estimates from Piping Fatigue/Usage Analysis

Component	Hatch Unit	CUF at 40 Years	Residual Margin at 40 years, %	CUF at 60 Years	Residual Margin at 60 years, %
Residual Heat Removal Suction Piping	2	0.57	43%	0.77	23%
Reactor Vessel Equalizer Piping	1	0.52	48%	0.64	36%
Core Spray Replacement Piping	1	0.16	84%	0.19	81%
Feedwater Piping	2	0.61	39%	0.83	17%
Standby Liquid Control Piping	1	0.24	76%	0.25	75%
Feedwater (FW), High Pressure Coolant Injection (HPCI), Reactor Core Isolation Cooling (RCIC), and Reactor Water Cleanup (RWCU) Piping	1	0.56	44%	0.72	28%
Steam Condensate Drainage Piping	2	0.66	34%	0.89	11%

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Margin Estimates from Time Limited Aging Analysis of Vessel Irradiation Damage

Relative Residual Margin (@1000 psig) = $[1 - \frac{(T\text{-Limit}) - 157}{157}]$

Core-critical operation with heatup/cooldown rate at 100° F/hr	Belt-line @ 1000 psig	
	T-Limit	Relative Residual Margin, %
Min. Temperature @ 54 EFPY	331.4° F	7.8
Min. Temperature @ 48 EFPY	323.6° F	12.3
Min. Temperature @ 44 EFPY	317.9° F	15.6
Min. Temperature @ 40 EFPY	311.7° F	19.2
Min. Temperature @ 36 EFPY	305.2° F	23.0

Nil-irradiation damage T-Limit taken to be 157° F

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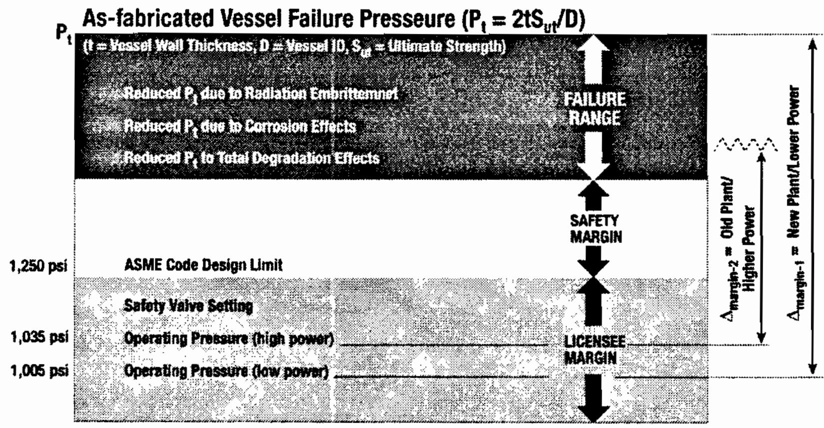
Illustration of Margin Concept for Reactor Vessel, as Used in the Regulatory Process



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Recent Events with Margin Reductions

- **Susquehanna-2**: weld failure in sensing line of recirculation system, due to increased vibrations associated with increased recirculation flow at 4.5% power increase.
- **Quad Cities-2**: steam dryer/cover-plate failure due to flow induced vibrations (17.8% power increase, ~22-% steam flow increase)

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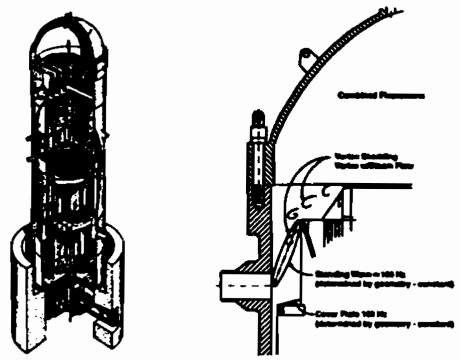
Quad Cities - 2
Steam Dryer Failure Event



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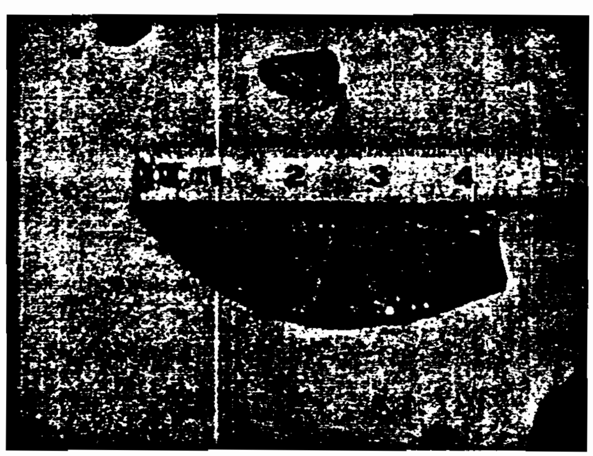
Quad Cities - 2
Fragmented Cover Plate
Remains Found in Strainer



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Summary/Conclusions

- Margin reductions to component design limits were noted for both power uprates and license renewal. Although plant-to-plant variations exist, generic margin reductions are evident owing to longer component duty times and higher operational conditions.

- This study points to the need for more information with regard to margin impact on individual components and the plant as a whole, particularly for power uprates. The development of a Standard Review Plan (SRP) for uprates, with regulatory guidance on margin impact, would go a long way in remedying this situation. On the other hand, SRP guidance for License Renewal, exemplified by aging/fatigue analysis requirements for passive components, provide transparency for assessing margin impact for plant life extensions.

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Summary/Conclusions (Cont'd)

- Margin estimates presented here were for individual components and separate licensing actions. No attempt was made to translate component-specific margins to that for the plant as a whole, or to assess the compound effects of multiple licensing actions. With some development, PSA techniques could provide a more integrated assessment of margin impact. Such margin integration efforts are recommended.

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