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

Feb. 20, 2002

MEMORANDUM TO: Bonaca, Bahadur, Larkins

MEMORANDUM #: AWC-103.2002

FROM: A. W. Cronenberg

SUBJECT: Estimated Efforts for Closure of ACRS Project Related to *Margin Impact for Multiple Licensing Actions*

NOTE: This memo is prepared per request of Drs. Larkins and Bonaca, to formulate a "closure plan" regarding prior efforts at evaluation of the margin impact and associated safety implications of plants requesting multiple licensing actions, specifically power uprates, license renewal, and extended fuel cycle to higher burnup. The principal documentation of prior efforts include:

Report-AWC-105.2001: *Margin Reduction Estimates for The Re-Licensed/Uprated Hatch-BWR Plant*
ICONE10 Paper: *Margin Impact Estimates for Re-Licensed/Uprated Plants: Hatch Case Study*

Critical comments on the ICONE10 paper were received from both NRR and the licensee, Southern Nuclear Operating Co; which we believe are largely related to a broad misunderstanding of the central focus of this work. A plan of action is thus presented, to address such critique/concerns.

This plan is primarily developed for benefit of a *replacement ACRS-Fellow*, new to this effort. In this regard the memo provides a background of the work done to date, principal review comments/critique, a suggested plan to address such critique, outline of additional assessment efforts required for a more integrated evaluation of margin impact...including the effects of high fuel burnup (not addressed in last report). Suggested documentation format (NUREG report), estimated FTE effort, and location of all resource material (Cronenberg reports/paper, review comments, Hatch Plant Uprate and License Renewal documents, etc) are provided.

BACKGROUND: The critique comments received from both NRR and the Southern Nuclear Operating Co; primarily center on our estimation of margins to "design limits" for Hatch plant uprate and license renewal conditions. They comment that margins to "design limits" are licensee margin space, and so long as "design limits" are not violated, there is no reduction in margins to safety. We are well aware of this argument, indeed we do not refute it *per se*. Likewise, we are indeed cognizant of the large margin between ASME code limits for plant components and actual failure conditions. We tried to convey this message in Figure 1 of ICONE paper (*Illustration of Margin Concept for BWR Primary Coolant Piping, as Used in the Regulatory Process)* and associated discussions in the text. Somehow, this message was lost. Our contention remains that margins, in a broad sense, are indeed eroded as a consequence of component fatigue/aging/corrosion-erosion effects and resultant diminished failure conditions on one hand, and increased operational conditions on the other.

Figure A presents an illustration of the margin concept for BWR primary piping. The shaded area shows what is referred to as "licensee margin". The point continually made by licensees, is that so long as plant conditions remain below the ASME design limit, the "safety margin" is neither violated or changed; thus there is no safety implication, for say higher uprate piping pressures. This is one point of view, and we are not refuting the contention that the safety margin is violated.

Our perspective is best illustrated from the concept of a **"delta-margin"**, defined as:

Delta-Margin = [Actual Press. for Pipe Failure - Plant Operating Press.]

For a new plant, say Hatch, the original operating primary pressure was 1015 psi and the piping is assumed at a non-degraded condition; thus delta-margin-1 would apply in Figure A. Now compare this with conditions associated with the first power uprate, where the primary system pressure was increased by 35 psi to 1050 psi, and one can assume some reduced failure pressure due to pipe aging/corrosion effects. In this case delta-margin-2 applies. The overall margin, in a broad sense is thus narrowed, that is reduced, though neither the "design limit" or "safety margin" is violated. This is what we are trying to convey. The differences between the NRR/Licensee view of margin and our delta-margin, appears to be the crux of the misunderstandings.

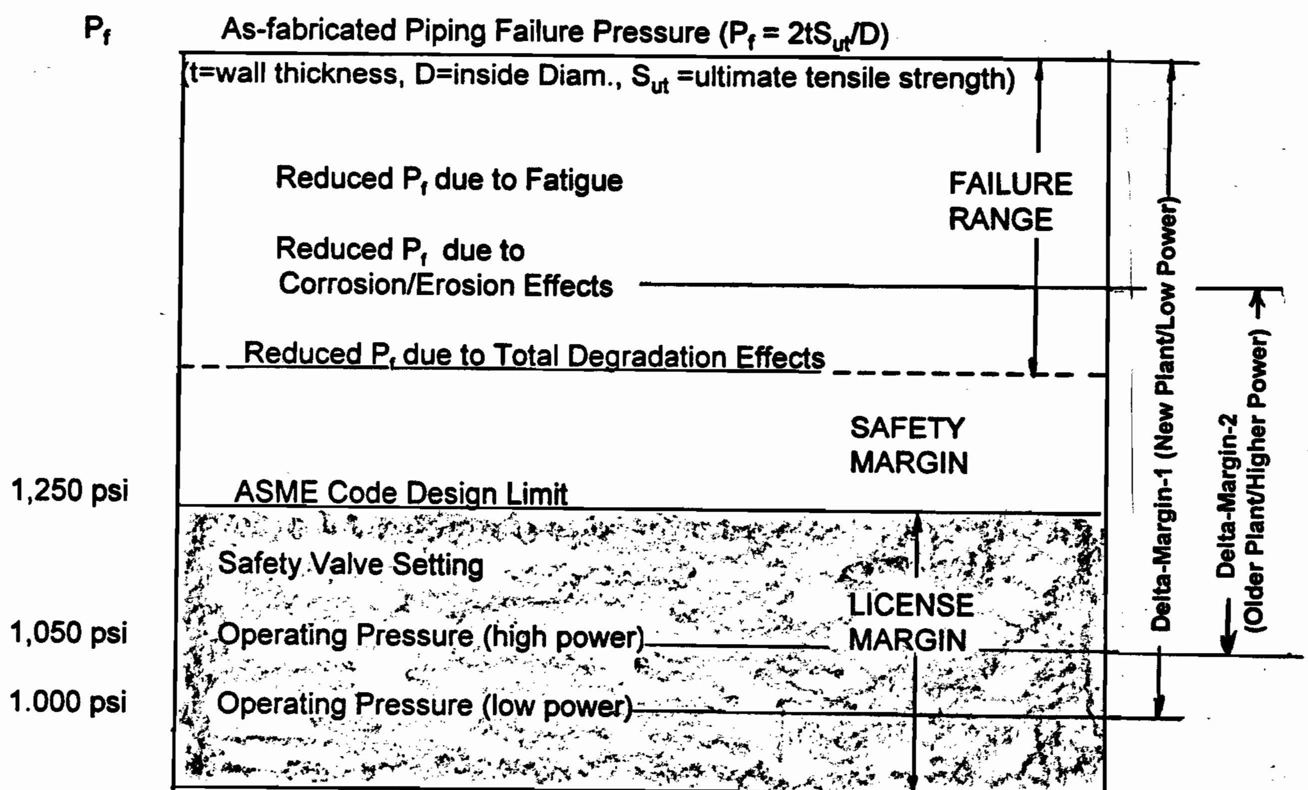

Figure-A. Illustration of "margin concept" for BWR primary system piping.

The above views need to be communicated in a much better manner. In addition, follow-on efforts should address all licensee/NRR review comments on the ICONE10 margins paper, as well as include the additional work previously recommended with regards to a holistic assessment of margin reductions on a system wide basis, translation of "reduced delta-margin" to risk space, and evaluation of the margin impact of fuel brought to high burnup conditions.

It is also recommended, that because of the sensitive nature of the subject, documentation might best be a NUREG-report, similar to the Jack Sorensen reports (**NUREG-1755**: Some Observations on Risk Informing Appendices A&B to 10CFR50:General Design Criteria; and**NUREG-1756**: Safety Culture...A Survey of the State-of-the-Art). A NUREG format is recommended to adequately convey the delta-margin concept and prior concerns; thus, hopefully avoid prior criticisms and misunderstandings.
A conference publication might be in order, after NUREG documentation.

Recommended Follow-on Efforts

1) Address all Hatch-Licensee/NRR Review Comments on ICONE10 Paper (FTE= 1.5 man-month):

Southern Nuclear Operating company provided a 2-page cover letter and 7-page attachment outlining, in considerable detail, their concerns/critique. Much of this critique centers on the narrow viewpoint of "safety margin" and "design limits", rather than the "delta-margin" concept we are talking about (refer to above discussion and Figure A). Similar misunderstandings are evident from the NRR comments. The different viewpoints of "margin" need to clearly addressed.

In addition to addressing prior critique, a more detailed discussion of "Safety Factors" inherent in the ASME Boiler & Pressure Vessel Code is suggested. Although our prior report did make note of such factors of safety, it was done in a rather casual manner. I believe it may be necessary to delve into the ASME Code and annunciate the specific Safety Factor for each Hatch plant component we examined (main steam-line Temp., main steam-line Press., shroud support weld stress, shroud head bolt stress, access hole cover plat bolt stress, etc). In a similar vain, the ASME Code also provides Safety Factors with respect to Cumulative Usage Factors (CUFs) for the various Hatch components examined in this margin study (core spray piping, feed-water piping, HPCI and RCIC piping, etc) with regards to plant aging/license renewal, which likewise need to be more adequately documented. Although this will involve a somewhat tedious/time-consuming effort, if such factors-of-safety are clearly spelled out, the reader might more readily accept that we have considered such in our examination of margins.

There are a host of other comments, that I believe will need to be addressed, one-by-one, if we are to get reasonable acceptance of this study. A minimum effort, of 1.5 FTE man-months is estimated.

2) Integrated Assessment of Margin Impact for Multiple Licensing Actions (FTE = 4.0 man-months)

Systems Integration: This effort would involve an integration of margin reduction estimates for individual components (Phase-I effort) into an assessment of the margin impact on a*system-wide basis*. For example, the margin impact for the Hatch plant primary coolant system would be estimated, rather than simply for the primary piping. In other words a holistic estimate would be made for the combined primary system of jet pumps, valves, piping, core shroud, etc. In its simplest form such an integrated margin (IM) estimate might be defined as: $IM = (1 - MR_1)(1-MR_2)(1-MR_3)....(1 -MR_n)$, where MR_x are the percent margin reductions for each component comprising the system. Likewise, a similar assessment could be made for the BWR containment system; i.e. torus suppression pool, suppression pool piping, dry-well, condensate storage tank, etc. It is noted that a more thorough examination of each system will be necessary then was the case for the Phase-I study, where ASME design limits for just a few components were cited in Phase-I study from readily available documents.

In addition to a more holistic assessment of margin impact for the plant, Dr. Bonaca has indicated that he would like to examine the impact of component age degradation that is currently being investigated by ASME and being proposed for inclusion in Design Limits in the ASME Boiler & Pressure Vessel Code.

Khatib-Rahbar Risk Matrix: A recent paper by Khatib-Rahbar ["*Risk-Impact of Reactor Power Upgrade for a BWR....*"] examined the risk impact associated with a 15-% power increase for the Swiss Leibstadt-BWR plant; where the risk matrix was based on an estimation of the reduced operator response time to a core uncovery event associated with the power uprate. It is of particular note that the algorithm they used to estimate margin reduction was quite simple, nevertheless it illustrated the point that some decrease in safety margin can be expected. They assumed that an increase in reactor power level would impact safety margin by an increase in the decay heat load and thus a reduction in time to core uncovery for a severe accident, assuming all other factors equal (same core coolant inventory, same decay heat removal capacity, etc. as with prior lower power level). Making use of the simple algorithm that the decay power and time to core uncovery (t_{uc}) is inversely proportional to core operating power (Q) to the 1.43 power, a reduction in time for uncovery (and thus time for operator remedial action) was estimated for the 15-% power increase proposed for the Swiss Leibstadt-BWR plant:

$$(t_{uc}) = (1/Q)^{1.43} = (1/1.15 = 0.87)^{1.43} = 0.81$$

or a core uncovery time which was 19-% less for the 15-% power increase. From PSA models they deduced a corresponding increase the CDF by about 30-% for this reduction in uncovery time. They also note a similar power-dependence can be shown for containment failure time (due to containment over-pressurization) and thereby the time of fission product release to the environment.

Although we cite the Khatib-Rahbar study in our prior report and ICONE10 paper, we did not attempt any similar type estimation of risk for our case study, i.e. for the Hatch at 5-% and 8-% power uprates. In the follow-on effort, it is proposed to quantify risk for the Hatch uprates, using the same algorithms as those provide by Khatib-Rahbar for the Leibstadt uprate.

High Fuel Burnup Effects: The prior study did not include an evaluation of the margin impact of high fuel burnup, although all plants that have recently requested power uprates and license renewal, indicate expected peak burnups approaching the current regulatory limit of 62,000 MWD/t-U.......which is well above the data base for fuel behavior under DBA-LOCA conditions (more like 20,000 MWD/t-U). An assessment of high-burnup effects on the "delta-margin" concept is suggested in this follow-on One might estimate such a burnup-margin effect from examination of the increase in fission product inventory and therefore source term associated with higher burnup conditions. Table-A presents ORIGIN predictions of decay power, which is a measure of fission product inventory. Two burnup conditions are shown, 33 GWD/t and 55 GWD/t, for similar initial enrichment (3.3-% U235) and irradiation history. Predictions are given for the decay power for both light elements and actinide decay products, as well as their sum. The salient point to note is that the decay power, and thus fission product inventory, is clearly higher for the 55 GWD/t case than for 33 GWD/t, which would manifest as a higher TIDE (Total

Integrated Dose Equivalent) for site exclusion boundary calculations, or for that matter public exposure estimates. For comparison purposes we can see that for a 10 day cool-off period the 33 GWD/t case yields a decay value of about 0.619 E+4 (W/MT) versus 1.018 E+4 for the 55 GWD/t burnup case; thus a 64-% increase in decay power (or approximate fission product inventory) for a 67-% increase in burnup. Clearly there is an almost direct proportionality of an increase in decay heat and fission product inventory with burnup, which can be correlated to an increase in site worker or public exposure risk, all other factors being equal.

An algorithm for the impact of higher fuel burnup on margin might also be assessed from consideration of the degradation of cladding mechanical properties due to the longer fuel duty time associated with extended burnups. For example let us assume a threshold dependence on Zircaloy cladding failure with burnup level, as implied from several in-pile test resultsfor Design Basis Reactivity Insertion Accidents (RIA). Such tests indicate RIA associated Zircaloy cladding failures due to loss of ductility via oxidation (Zr-Ox) and attendant hydrogen uptake. For illustrative purposes let us assume a threshold dependence, say at 40 GWD/t, with the following algorithm:

$$\text{Zr-Ox} = \{1 - [\text{X-Burnup}/40\ \text{GWD}]^{0.3}\}$$

Let us compare predictions at 50 GWD/t and 62 GWD/t (present NRC burnup limit) and compare them to the NRC allowable oxidation limits for Design Basis conditions (i.e. 17-% oxidation limit):

$$\text{Zr-Ox} = \{ 1 - [50/40= 1.25]^{0.3} \} = 7\text{-\% oxidation}$$

$$\text{Zr-Ox} = \{ 1 - [62/40= 1.55]^{0.3} \} = 14\text{-\% oxidation}$$

Although neither burnup violates the regulatory oxidation limit of 17-%, one might reasonably ascribe an increase in Zircaloy oxidation with an attendant loss of cladding ductility (let us say for example a linear dependence), which could translate to some increase in clad failure potential and thus a reduced safety margin. Although such examples are used here for demonstrative purposes only; they do indicate the type of approaches that might be used to quantify burnup margin effects. Simple statistical models might then be employed to estimate the synergistic (compound) effect of several licensing actions (i.e. power uprate + burnup increase + plant life extension).

Table A: ORIGIN Predictions of Decay Power

Cooling Time	3.3% ^{235}U, 33 GWD/MTU — Afterheat Power (W/MTU)			3.3% ^{235}U, 55 GWD/MTU — Afterheat Power (W/MTU)		
	Light Element	Actinide	Sum	Light Element	Actinide	Sum
10d	5.8755(+2)	5.6055(+3)	6.1931(+3)	7.4920(+2)	9.4328(+3)	1.0182(+4)
30d	5.1581(+2)	1.8079(+3)	2.3237(+3)	6.6379(+2)	4.9161(+3)	5.5799(+3)
60d	4.3205(+2)	1.5297(+3)	1.9618(+3)	5.6381(+2)	4.3434(+3)	4.9072(+3)
90d	3.6540(+2)	1.3711(+3)	1.7365(+3)	4.8433(+2)	3.9413(+3)	4.4256(+3)
120d	3.1252(+2)	1.2351(+3)	1.5476(+3)	4.2129(+2)	3.5913(+3)	4.0126(+3)
180d	2.3919(+2)	1.0105(+3)	1.2497(+3)	3.3374(+2)	3.0120(+3)	3.3457(+3)
365d	1.5390(+2)	5.9003(+2)	7.4393(+2)	2.3006(+2)	1.9226(+3)	2.1527(+3)
730d	1.2126(+2)	3.1492(+2)	4.3618(+2)	1.8547(+2)	1.1932(+3)	1.3787(+3)
1825d	7.9164(+1)	2.4980(+2)	3.2896(+2)	1.2164(+2)	9.5697(+2)	1.0786(+3)
10y	4.0343(+1)	2.6046(+2)	3.0080(+2)	6.2082(+1)	8.8603(+2)	9.4811(+2)

NUREG-Documentation (1.5 FTE man-months)

It is recommended, that because of the sensitive nature of the subject and prior critique/misunderstandings, the deliverable for documentation of results might best be facilitated by initial publication as a NUREG-report, similar to the Jack Sorensen reports (**NUREG-1755**: Some Observations on Risk Informing Appendices A&B to 10CFR50:General Design Criteria; and **NUREG-1756**: Safety Culture...A Survey of the State-of-the-Art). A NUREG format is recommended, in view of the anticipated depth of discussion and considerations required to adequately convey the delta-margin concept and hopefully avoid some of the prior criticisms. A conference publication might be in order after NUREG documentation. Documentation efforts as a NUREG, are estimated at 1-2 FTE man-months, largely depending on level of review process.

FTE Man-month Effort

Address NRR/ICONE Comments	= 1.5 man-months FTE
Margin Integration Efforts	= 4.0 man-months FTE
NUREG Documentation	= 1.5 man-months FTE
Total	= 7 man-months FTE

Listing of Resources & Location for New ACRS-Fellow:

See 2-BOXES Marked: **Margins Resource Material**
See Theron: Boxes located in mail-room/last row of shelves

Includes:
- Cronenberg Memos/Progress Reports
- INCONE10 paper & all review comments
- Hatch Documents:
  - LAR/SERs for 2 Power Uprates
  - License Renewal Application/SER
- License Renewal SRP & Reg. Guides
- BWR-VIP Reports
- Leibstadt PSA for 14.7-% Power Uprate

Appendix-A/Memo-103.2002

Closure Efforts for ACRS Project on Margin Impact for Multiple Licensing Actions

Ideas for Translation of Delta-Margin Concept to Risk Space
Using Component Failure Data

Besides critical comments from NRR and the Southern Nuclear Operating Co on our use of "design limits" to infer margin reductions, both indicated that our ICONE10 paper failed to make a direct linkage of reduced margins to increased Risk. This is a legitimate argument, in that we did not quantify any increased risk from our Hatch examples; rather we referred to the Khatib-Rahbar paper, which examined the risk impact associated with a 15-% power increase for the Swiss Leibstadt-BWR plant. They assessed a delta-risk increase from estimation of the reduced operator response time to a core uncovery event associated with the power uprate. We did mention this work in our ICONE10 paper, but the point seemed to be lost on the readers.

In the body of this memo, I cite a simple algorithm for increased decay power with power level (power uprate) and the associated reduced time to core uncovery, similar to that used by Khatib-Rahbar to infer risk for uprated conditions. Although I suggest we apply such a model to the Hatch uprate conditions to infer a delta-increase in Risk for uprated conditions, this may not be totally convincing. To make a stronger case, I suggest we also examine component failure data to support our case, as briefly outlined here.

Using the Hatch plant uprate as an example, we could compare say the estimated piping failure probability at conditions associated with the original license in 1977, with the failure probability for the same piping at conditions associated with the first power uprate in 1995. For example, the original license for the Hatch plant was at primary pressure of 1015 psi, a main steam-line temperature of 546 F, and the piping was new in 1977, i.e. at a non-degraded condition. Now compare this for the same piping at conditions for the first power uprate, where the primary system pressure was increased to 1050 psi, the main steam-line temperature increased to 548 F, and the piping aged by 18 years (first uprate =1995). We would therefore seek piping failure frequency data for the newly licensed conditions, compared to failure frequency data for the same pipe aged by 18 years and at somewhat higher temperature/pressure conditions for the uprate. If we can find piping failure data showing an increase, then clearly Risk is increased, even if consequences remain the same:

Risk (Consequences/yr) = [Failure/yr] X (Consequence/Failure)

This is but an illustrative example, but I use it in view of the large body of failure date for piping ((*EPRI Report: Nuclear Reactor Piping Failure Data for US Commercial LWRs, TR-110102, 1998*). Likewise, I note the 1999 *Susquehanna-BWR event*, where pipe weld failure occurred in the re-circulation line following a power uprate, where the root-cause has been associated with increased pipe vibration at the higher re-circulation pump speed for uprated conditions (this was NRC evaluation and indicated a generic concern; GE has said event was plant specific, not a generic uprate concern).